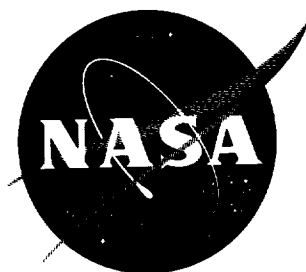


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TECHNICAL NOTE

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EXPERIMENTAL DETERMINATION OF SPECTRAL AND TOTAL
TRANSMISSIVITIES OF CLOUDS
OF SMALL PARTICLES

By Chester D. Lanzo and Robert G. Ragsdale

Lewis Research Center
Cleveland, Ohio

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SUMMARY

Measured values of spectral and total transmissivities of clouds of small particles were obtained for carbon, tungsten, aluminum oxide, and hafnium carbide. The particles were dispersed in distilled water to decrease settling rates. Spectral values are presented for wavelengths from 0.2 to 1.0 micron. Particle densities ranged from 10^{-6} to 10^{-4} gram per cubic centimeter of dispersion and particle diameters from 0.02 to 2.0 microns. Spectral measurements were made with a recording spectrophotometer. A xenon arc lamp and a radiation detector were used to obtain total transmissivities.

The transmissivity measurements indicate that Beer's law is operative; that is, transmissivity varies exponentially with particle density. The transmissivity of carbon particles 0.08 to 1.4 microns in diameter was independent of wavelength for the range from 0.2 to 1.0 micron. A correlation of extinction coefficient per particle as a function of particle radius is presented.

For constant particle weight per unit volume of dispersion, the transmissivity of carbon particles exhibited a minimum for a particle radius of 0.3 to 0.4 micron. In general, for a given weight of particles per unit volume and a given particle size, carbon particles gave the least transmissivity, while aluminum oxide, hafnium carbide, and tungsten gave successively larger transmissivities. Light intensity measurements indicated that the attenuation of radiation by the carbon particles is the result of true absorption and not scattering.

The measured transmissivity of 1.4-micron-diameter carbon particles indicated that a particle density on the order of 10^{-4} gram per cubic centimeter will absorb 98 percent of all radiation in the wavelength range from 0.2 to 1.0 micron in a path of 10 centimeters.

INTRODUCTION

Radiative heat transfer is an important consideration at the temperature levels associated with current and advanced nuclear-rocket concepts. It can be shown, for example, that radiation is the primary mode of energy transfer to the hydrogen propellant in a coaxial-flow gaseous nuclear rocket (ref. 1).

Since hydrogen is transparent at temperatures below 5000° K (ref. 2), the necessity of seeding it with an absorbing material is obvious. Carbon and hafnium carbide particles are examples of possible seeding materials. Estimates based on the calculated emissivity of dispersed carbon particles (ref. 3) indicate that an acceptably small concentration of a seeding material should make hydrogen sufficiently opaque to protect the reactor walls. Of course, many complex problems are attendant to the use of high-temperature seeded hydrogen gas as a propellant. The combined effects of wavelength and particle-size dependence, scattering, chemical reaction at elevated temperatures, and nongray gas characteristics are not sufficiently understood to permit a rigorous radiation analysis. A recent study of hydrogen radiative properties is given in reference 4.

Some experimental data are available for heat transfer to particle clouds (ref. 5), but these data are for relatively low temperatures. Reference 6 gives a generalized procedure for the determination of particle size distribution of industrial flue products by photoextinction. An analytical and experimental study of the emissivity of a seeded gas is presented in reference 7 for commercial-furnace temperature levels and particle sizes larger than 10 microns.

A means of estimating the required seeding densities in a gaseous reactor was provided by a study of the transmissivity of particle clouds at room temperature. This investigation was undertaken at the Lewis Research Center and was conducted in two phases: (1) Spectral transmissivity measurements were made with a spectrophotometer; (2) total transmissivity was determined with a xenon-arc source and a radiation detector. In all tests the sample powders were dispersed in distilled water, which minimized problems caused by particle settling. The absorption contribution of the water was eliminated by comparing the transmissivity of each sample cell with that of a reference cell which contained only water.

Although carbon particles were used in obtaining most of the data, some values for hafnium carbide, aluminum oxide, and tungsten powders are also presented. Four carbon powders, Ax coke, Carbolac, lampblack and Monarch carbon, were used to investigate the effects of particle size on transmissivity.

Figure 1 illustrates the particle system to be investigated. Radiant energy of intensity I_0 and wavelength λ traverses the particle cloud for a distance l and is attenuated to the emerging intensity I . The particle system is defined by N the number of particles per unit volume of dispersion, $\bar{\rho}$ the particle density, and R the particle radius. The purpose of this investigation was to determine the interdependence of these parameters over the particle-size and wavelength ranges of interest and to provide information for facilitating the estimation of the transmissivity of a seeded medium.

All the data are presented in the form of transmissivities. If no radiation is removed from the incoming beam by scattering, these values are readily transformed into absorptivities. The problem of scattering is treated in detail in reference 8 and, in general, is not a factor for the range of conditions considered here. Some brief measurements for verification are included herein.

SYMBOLS

A	particle cross-sectional area, $\text{cm}^2/\text{particle}$
D	particle diameter, microns
E	specific extinction coefficient, cm^2/g
I	transmitted intensity
I_0	incident intensity
I/I_0	transmissivity
l	path length, cm
N	particle concentration, particles/cc of dispersion
R	particle radius, cm
ϵ	extinction coefficient, cm^{-1}
λ	wavelength, microns
ρ	material density, g/cc
$\bar{\rho}$	particle density, g/cc of dispersion
σ	absorption cross-sectional area, $\text{cm}^2/\text{particle}$

APPARATUS AND PROCEDURE

Spectral Transmissivity

Spectrophotometer. - Spectral transmissivities of the various particles were measured with a recording spectrophotometer, which provided the following features: a quartz monochromator, with either a hydrogen or tungsten lamp, and a photomultiplier or lead sulfide detector that gave a wavelength range of 0.2 to 2.7 microns. A dual-beam optical system eliminated window and suspension-medium transmission effects. The slit width was automatically regulated to provide constant light intensity at all wavelengths. A block diagram of the spectrophotometer is shown in figure 2.

Absorption cells. - The matched quartz cells used for the tests are 10 centimeters in length and 2 centimeters in diameter (fig. 3). The reference cell was filled with distilled water and the sample cell with distilled water containing a dispersion of the powder to be tested. In both the spectral and total-transmissivity measurements, the diameter of the light beam was small compared with the diameter of the cell.

Sample preparation. - A quantity of the powder to be tested was weighed on an analytical balance and dispersed in 500 milliliters of distilled water (typical sample weight, 0.01 g). The dispersion was then placed in an ultrasonic vibrator for 5 minutes. Finally, the sample cell containing the dispersion was put in a sieve shaker for 30 minutes to further homogenize the mixture.

Glass slides were used to obtain photomicrographs of evaporated droplets of each sample (fig. 4). The various powders tested and their respective particle diameters are given in the following table:

Material	Particle diameter, D, microns
Carbolac	0.08
Monarch	.15
Lampblack	.45
Ax coke	1.40
Aluminum oxide	.02
Tungsten	0.02, 0.032
Hafnium carbide	2.0

The particle sizes were obtained from a subsieve sizer that gives average spherical diameter of a given particle-size distribution.

It is of interest to note that the tungsten dispersions were prepared in two ways. One method consisted of weighing the tungsten powder in air and then placing it in the water. An alternate technique consisted of forming the dispersion in an argon dry box to prevent possible oxidation.

Total Transmissivity

The experimental apparatus used to determine total transmissivity is shown in figure 5(a); figure 5(b) is a schematic representation of the system. A 1/8-inch-diameter collimated beam from the xenon arc was first passed through a water-filled quartz reference cell and the emerging intensity determined. After this measurement was made, the procedure was repeated with a similar cell containing the test dispersion. The intensity of the emerging beam was measured with a Golay detector, which was mounted directly behind the sample cell. The detector output was passed through an amplifier to an indicating potentiometer. During one phase of the test, interference filters were inserted into the light path in front of the sample cell to obtain transmissivities over certain finite wave bands in the ultraviolet and visible regions.

Light source. - The 900-watt xenon arc lamp used as a radiation source in the total-transmissivity experiment has two unique properties that recommend its use in the ultraviolet and visible regions: First, the primary line spectra are in the infrared region; such lines as exist in the visible range are insignificant in energy content. Second, the continuum radiation has a distribution that closely approximates that of a blackbody at 7000°R . The actual spectral distribution of a xenon arc lamp taken from the manufacturer's data is shown in figure 6. Blackbody distribution curves for 5000° and 7000°R are also shown for comparison.

Radiation detector. - A Golay detector was used to measure the relative intensity of radiation transmitted through the cells. The detector has a linear response for the region investigated and operates in the following manner. A radiation-absorbing film is located in the center of a small gas chamber. The gas is heated by conduction from the film, which is illuminated by radiation. The expansion causes distension of a small flexible mirror. Displacement of the mirror is detected by an optical system in which an incandescent filament is imaged on the mirror, and the light reflected by the mirror is in turn reflected onto a photocell. A "chopper" is used to interrupt the light beam at 10 cycles per second, which in effect corresponds to resetting

the instrument at every interruption of the beam, and thus eliminate drift. The output of the photomultiplier is fed into an amplifier, which is connected to an indicating potentiometer with a 10-millivolt sensitivity (fig. 5(a)).

Interference filters. - A set of interference filters was used to obtain spectral transmissions of the xenon arc lamp, a water-filled cell, and a typical carbon powder size and concentration. Eight filters were used to cover a range from 0.2 to 1.0 micron. The transmission curves of these filters are shown in figure 7 and the specifications are listed in the following table in terms of λ_{peak} , $(I/I_0)_{\text{peak}}$, and $\lambda_{50 \text{ percent}}$, where λ_{peak} is the wavelength for which the filter has maximum transmissivity $(I/I_0)_{\text{peak}}$, and the two values listed under $\lambda_{50 \text{ percent}}$ are the wavelengths on either side of the peak at which the transmissivity is one-half of $(I/I_0)_{\text{peak}}$:

Filter	Wavelength, λ_{peak} , microns	Maximum transmissivity,	
		$(I/I_0)_{\text{peak}}$	$\lambda_{50 \text{ percent}}$
1	0.240	0.200	0.230 to 0.246
2	.304	.170	.299 to .313
3	.395	.150	.392 to .398
4	.403	.160	.400 to .405
5	.425	.260	.421 to .426
6	.464	.460	.460 to .467
7	.638	.510	.631 to .643
8	.767	.570	.758 to .772

Scattering measurements. - A sample cell containing 0.36×10^{-4} gram per cubic centimeter of 0.08-micron-diameter carbon powder was used to determine the amount of light attenuation caused by scattering rather than by true absorption. The arc lamp, the Golay detector, and the quartz cells were used, and light intensities were measured with a brightness spot meter. A 1/8-inch-diameter collimated beam of light from the xenon arc lamp was passed through the sample. Measurements were made of the light intensity into the cell, as well as the intensities emerging from both the end and the side. For the side measurement a light meter was placed 6 inches from the cell normal to the incoming beam at the axial midpoint. The light collecting lens of the meter was 2 inches in diameter. The light passing straight through the sample was assumed to be a collimated beam; that is, the meter measured all the axially transmitted light. The total amount of scattered light was

calculated from the measured intensity with the assumption of isotropic scattering.

Data Reduction

Most of the data are presented in terms of the measured transmissivity I/I_0 as a function of particle density $\bar{\rho}$ or particle radius R . A general correlation expressing transmissivity in terms of R and N was obtained, as suggested in reference 9, from computation of an extinction coefficient ϵ :

$$\frac{I}{I_0} = e^{-\epsilon l}$$

From the measured particle density $\bar{\rho}$, particle material density ρ , and particle radius R , the particle concentration N is given by

$$N = \frac{1}{\frac{4}{3} \pi R^3} \frac{\bar{\rho}}{\rho}$$

The extinction coefficient per particle ϵ/N is then plotted as a function of particle radius. The material densities used are listed in the following table:

Material	Density, ρ , g/cc
Carbon	1.6
Hafnium carbide	12.3
Aluminum oxide	4.0
Tungsten oxide	7.16
Tungsten	19.3

The parameter ϵ/N can also be described as an "effective" or absorption cross section, denoted by the symbol σ .

RESULTS AND DISCUSSION

Spectral Transmissivity

Carbon particles. - Carbon particles suspended in water were placed in a sample cell, and transmissivity was measured at several intervals

to determine the change in transmissivity with time due to the settling of the larger particles. The results are shown in figure 8 for carbon particles of 0.08-micron diameter. The initial settling rate calculated from the slope of the curve in figure 8 indicates that a 1-percent change in transmissivity occurred in 36 seconds, which was sufficiently large compared with 10 seconds, the time required for a typical measurement.

A procedure of successive dilutions was used to determine the effect of particle concentration on transmissivity. The results for carbon particles are shown in figure 9, for particle diameters of 0.08, 0.15, 0.45, and 1.40 microns. Monochromatic light of 0.360-micron wavelength was used, and the path length was 10 centimeters.

The variation of transmissivity with particle concentration follows the exponential dependency predicted by Beer's law (see fig. 9):

$$\frac{I}{I_0} = e^{-E\bar{\rho}l}$$

where I/I_0 is the transmissivity, E is the specific extinction coefficient, $\bar{\rho}$ is the particle density, and l is the path length. The fact that Beer's law is operative suggests that E is a true absorption coefficient and that a large percentage of scattering is not present (ref. 10).

Figure 10 shows the extinction coefficient per particle ϵ/N as a function of particle radius. All the spectral carbon data from figure 9 were used to establish the representative line shown. Data points for all other materials tested are also plotted and show reasonable agreement with this line. Sufficient data were not available to determine whether a family of curves exists rather than one single line.

The slope of the dotted line drawn through the data at the left side of figure 10 is that expected from theoretical considerations (ref. 9) as the particle size approaches the region of Rayleigh scattering where $\epsilon/N \propto R^6$. The dashed line at the upper right side of the figure corresponds to $\epsilon/N \propto R^2$, which would be the anticipated slope for particles that are large enough to absorb by a simple "shutter" or blocking mechanism.

The oxidized tungsten data were omitted from figure 10 because the effect of oxidation on particle size was unknown. The tungsten data point, farthest from the line, is perhaps the most unreliable because of the possibility of oxidation during the tests. If the tungsten were assumed to be partly oxidized, the resulting change in material density

would move the data closer to the line. A seeding calculation is presented in the appendix to illustrate the use of figure 10 for a typical problem.

The correlation shown in figure 10 can be used to compare the relative seeding values of the various materials tested. For a particle diameter of 0.2 micron, the most absorptive particles per gram of seeding material per unit volume were carbon. Aluminum oxide, hafnium carbide, and tungsten yielded successively smaller absorptivities.

As pointed out in DATA REDUCTION, the function ϵ/N can be viewed as the absorption cross-sectional area per particle. A parameter of interest and some physical meaning is the ratio of the effective particle area σ to the actual particle cross-sectional area A . This ratio σ/A is shown in figure 11 for the four carbon powders. As the particle size increases, the ratio approaches unity. Physically, this means that each particle begins to act as an opaque shutter in the light path. The fact that σ/A approaches unity is just a restatement of the indication from figure 10 that ϵ/N is proportional to R^2 for large particles.

The line shown in figure 10 was used to calculate the variation of transmissivity with particle radius. Figure 12(a) shows curves for three particle densities, with data points taken from figure 9. For all three densities, a particle size of approximately 0.3 micron gives a minimum transmissivity (similar results for zinc oxide pigment suspended in water is reported in ref. 11). Figure 12(b) shows an alternate plot of transmissivity as a function of diameter for constant particle concentration (particles/cc).

The transmissivity of carbon was measured over a range of wavelength with the spectrophotometer. The results for a particle size of 0.15 micron are shown in figure 13(a). The transmissivity of the carbon powder is seen to be independent of wavelength from 0.2 to 1.0 micron for particle densities from 0.015×10^{-4} to 0.240×10^{-4} gram per cubic centimeter.

A crossplot of these data is given in figure 13(b), which shows the variation of transmissivity with particle density. This curve is the same as the curve in figure 9, except that these data are for all wavelengths from 0.2 to 1.0 micron, whereas the curves in figure 9 were for a wavelength of 0.36 micron and four particle sizes.

Noncarbon particles. - Figure 14(a) shows the transmissivity of 0.02-micron aluminum oxide as a function of wavelength. The traces are for wavelengths from 0.2 to 0.45 micron and particle densities from

0.029×10^{-4} to 0.922×10^{-4} gram per cubic centimeter. The transmissivity of the aluminum oxide particles decreases at the shorter wavelengths; a similar trend was observed with tungsten oxide particles.

The transmissivity of 0.02-micron tungsten powder suspended in distilled water is shown in figure 14(b) for wavelengths from 0.2 to 0.45 micron. The transmissivity is relatively independent of wavelength. The tungsten particles were weighed and the dispersions formed in an argon atmosphere.

A second tungsten dispersion of 0.032-micron tungsten was prepared by weighing in air and then forming the dispersion. When the transmissivity measurements indicated a dependence on wavelength similar to that of aluminum oxide, it was suspected that the tungsten had oxidized in air during the weighing operation. A third sample of 0.032-micron tungsten was weighed and dispersed in the dry box to check the possibility of oxidation.

Figure 15 shows the transmissivity of the 0.032-micron tungsten samples prepared by the two techniques. The transmissivity of the 0.032-micron tungsten particles prepared under argon is relatively independent of wavelength, as was the 0.02-micron tungsten, but the 0.032-micron tungsten prepared in air showed a decrease in transmissivity at the shorter wavelengths. Since the aluminum oxide transmissivity exhibited a similar behavior, it is assumed that the tungsten particles prepared in air were at least partly oxidized.

The transmissivities of the noncarbon materials were determined for various particle concentrations at a wavelength of 0.36 micron. The tungsten, aluminum oxide, and hafnium carbide particles all obey Beer's law, as shown in figure 16.

Total Transmissivity

Arc temperature distribution. - A xenon arc lamp was used as a source of radiation for total-transmissivity measurements. A small target optical pyrometer was used to measure the arc temperature distribution. The uncorrected temperatures are shown in figure 17. The "hot spot" near the cathode was beyond the range of the pyrometer, but manufacturer's data for the maximum arc temperature are presented for this value.

Transmissivity measurements. - The arc setup shown in figure 4 was used to measure total transmissivity as a function of particle density. The total transmissivities of the four carbon powders and the three tungsten powders are shown in figure 18. These values show the same

variation with particle density as was determined with the spectrophotometer, which indicates that Beer's law is applicable for the total transmissivities.

Spectral transmissivity of 0.08-micron-diameter carbon particles was determined by using a series of interference filters and the arc lamp as a source. Since the carbon transmissivity data from the spectrophotometer were independent of wavelength, the spectral transmission of the arc light through the dispersion could be predicted.

The spectral distribution of the arc lamp, taken from manufacturer's data, was multiplied by the transmissivity of the carbon dispersion under test. Figure 19(a) shows the arc distribution and the predicted distribution of the light transmitted through the sample. Figure 19(b) shows these distribution curves normalized to $I_0(\lambda)$. One curve was obtained from the spectrophotometer results and the other from the total transmissivity data. The spectral transmissivities through the interference filters are in good agreement with the line calculated from the total transmissivity measurements and the assumption of constant transmissivity.

Scattering measurements. - Some photometric measurements were made to determine how much of the attenuation through a typical carbon dispersion was a result of scattering rather than a result of true absorption. A 1/8-inch-diameter collimated beam from the arc lamp was passed through a dispersion of 0.08-micron carbon. Figures 20(a) and (b) show an end and a side view, respectively, of the light beam in the carbon dispersion. The fact that the cylinder of light remains well defined throughout the dispersion indicates that scattering is not present to any appreciable extent. Because the photograph from the side of the cylinder required an exposure time of 30 minutes compared with 5 seconds for the end view, the apparent relative intensities do not permit a visual comparison.

A light meter was used to measure the light intensity transmitted:

- (1) Axially through a water-filled cell
- (2) Axially through a dispersion-filled cell
- (3) Radially from the dispersion cell

Since the scattered radiation measured from the side of the cell was only that portion intercepted by the 2-inch lens at a distance of 6 inches, it was corrected to the total amount of side radiation by assuming isotropic scattering. This assumption is reasonable since the particle spacing is on the order of 150 particle diameters (ref. 8).

From the measured light intensities, the attenuation occurs in the following proportions:

Light	Transmissivity, I/I_0 , percent
Source	100
Transmitted	8.6
Scattered	1.3
Absorbed	90.1

The percentage of scattered light is a maximum value based on the minimum response of the instrument. The actual value may be orders of magnitude less, but 1.3 percent is the maximum amount of scattering. The conclusion here is that the attenuation of light by the various dispersions was a result of actual absorption and not a result of scattering.

SUMMARY OF RESULTS

Measured values for the spectral and total transmissivities of four carbon powders, ranging in diameter from 0.080 to 1.40 microns; and aluminum oxide, tungsten, and hafnium carbide, ranging in diameter from 0.02 to 2.0 microns dispersed in distilled water, were obtained. Transmissivities were obtained over the transparent wavelength region of water from 0.2 to 1.0 micron.

For the wavelengths and particle ranges tested:

1. All transmissivity measurements produced exponential dependence with particle density, hence Beer's law was applicable.
2. The transmissivity of carbon particles in suspension was independent of wavelength from 0.2 to 1.0 micron.
3. The oxides of tungsten and aluminum had a wavelength dependency that decreased in transmissivity at the shorter wavelengths.
4. Attenuation as a result of scattering was negligible.
5. The spectral transmissivities of all particles was represented by a single line, which showed the variation of extinction coefficient per particle ϵ/N as a function of particle radius.

6. When the ϵ/N correlation was used, the least transmissivity or most absorptivity per gram of seeding material per unit volume for a particle diameter of 0.2 micron, occurred in the order: (1) carbon, (2) aluminum oxide, (3) hafnium carbide, (4) tungsten.

CONCLUDING REMARKS

Throughout the report, some aspects of the application and usefulness of the data were briefly mentioned. It was felt appropriate to collect them for further comment.

Carbon particles used in this investigation were obtained from two different manufacturers; therefore, the composition and purity may not be similar because of different processing techniques.

In some of the early experiments with particles suspended in gas, settling rates were too high to produce satisfactory data. Water was chosen as a suspension medium to increase the length of time the particles were in the light path. Water is transparent in the 0.2- to 1.0-micron-wavelength region, which is the region of greatest interest for the proposed application.

It is reasonable to assume that carbon suspensions at room temperature will not duplicate the transmissivity results that occur at elevated temperatures in a gaseous medium such as hydrogen, but these results do indicate that radiation attenuation results from carbon particle seeding densities sufficiently small to be of interest for possible gaseous reactor concepts.

All particle sizes were measured using a subsieve sizer. Although the particle sizes might not be accurate in absolute value, the use of a consistent measurement technique should give relative results. Even though a reasonably elaborate procedure was used to form the dispersions, particle agglomeration may have influenced the measurement of particle size.

The measurements of this report are related to the seeding problem in a gaseous reactor; this is not to say, however, that the particles tested are necessarily the best for this purpose. The materials considered here were commercially available at the time of the tests; other materials may ultimately prove to be more useful than the ones investigated to date. For example, the choice of a seeding agent may be dictated by the minimum particle size attainable with various materials.

Lewis Research Center

National Aeronautics and Space Administration

Cleveland, Ohio, June 22, 1962

APPENDIX - SEEDING CALCULATION WITH

$$\epsilon/N = f(R) \quad \text{CORRELATION}$$

A typical calculation is the determination of the seeding density required to attenuate a given radiant energy to 5 percent of its initial intensity in a path length of, for example, 100 centimeters. It is postulated here that 1-micron-diameter particles are available and that their material density is 3.0 grams per cubic centimeter. From the attenuation requirement

$$\epsilon = \frac{-\ln 0.05}{100} = 0.0299$$

For a particle radius of 5×10^{-5} centimeter, figure 10 gives

$$\epsilon/N = 7.8 \times 10^{-9}$$

which gives the required particle concentration as

$$N = 3.84 \times 10^6 \text{ particles/cc}$$

From this value and a material density of 3.0 grams per cubic centimeter, the required particle density is found to be

$$\begin{aligned} \bar{\rho} &= N \rho \left(\frac{4}{3} \pi R^3 \right) \\ &= (3.84 \times 10^6 \times 3.0) \left(\frac{4}{3} \pi \right) (0.5 \times 10^{-4})^3 \\ &= 6.04 \times 10^{-6} \text{ g/cc} \end{aligned}$$

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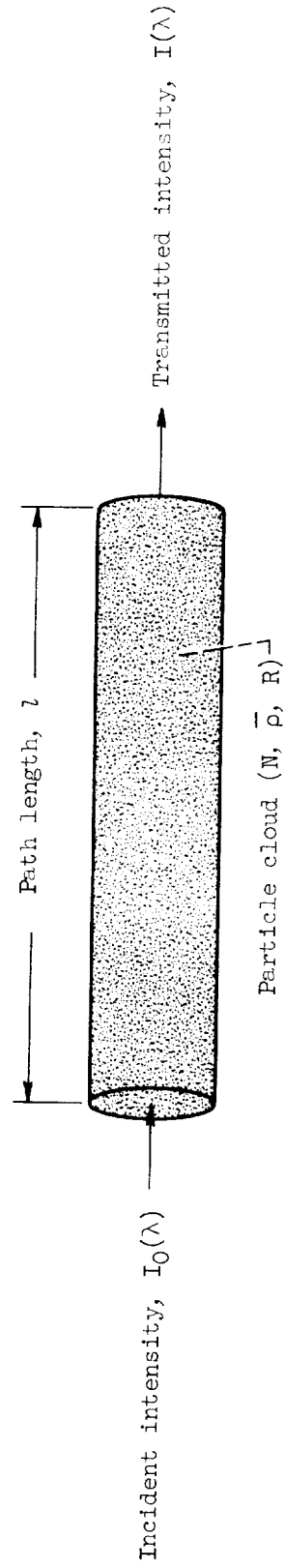


Figure 1. - Particle system for transmission measurements.

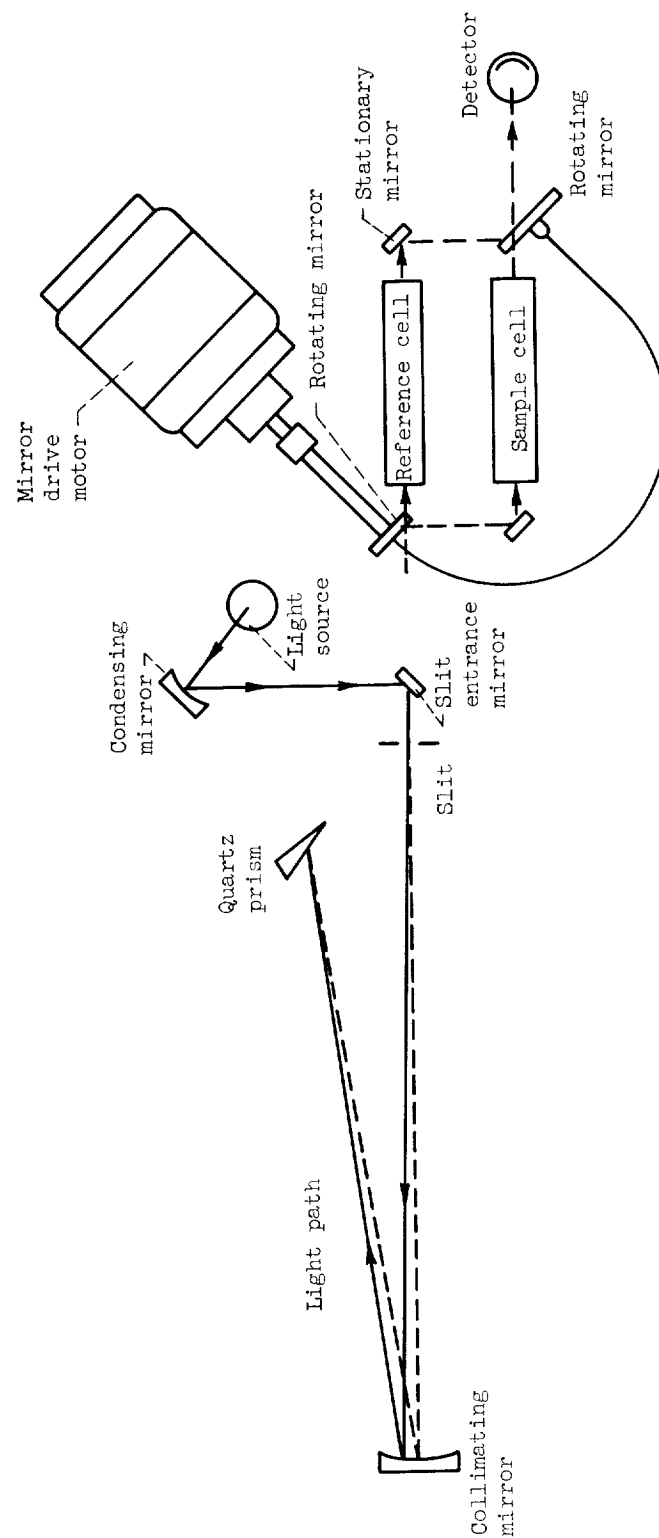


Figure 2. - Optical diagram of spectrophotometer.

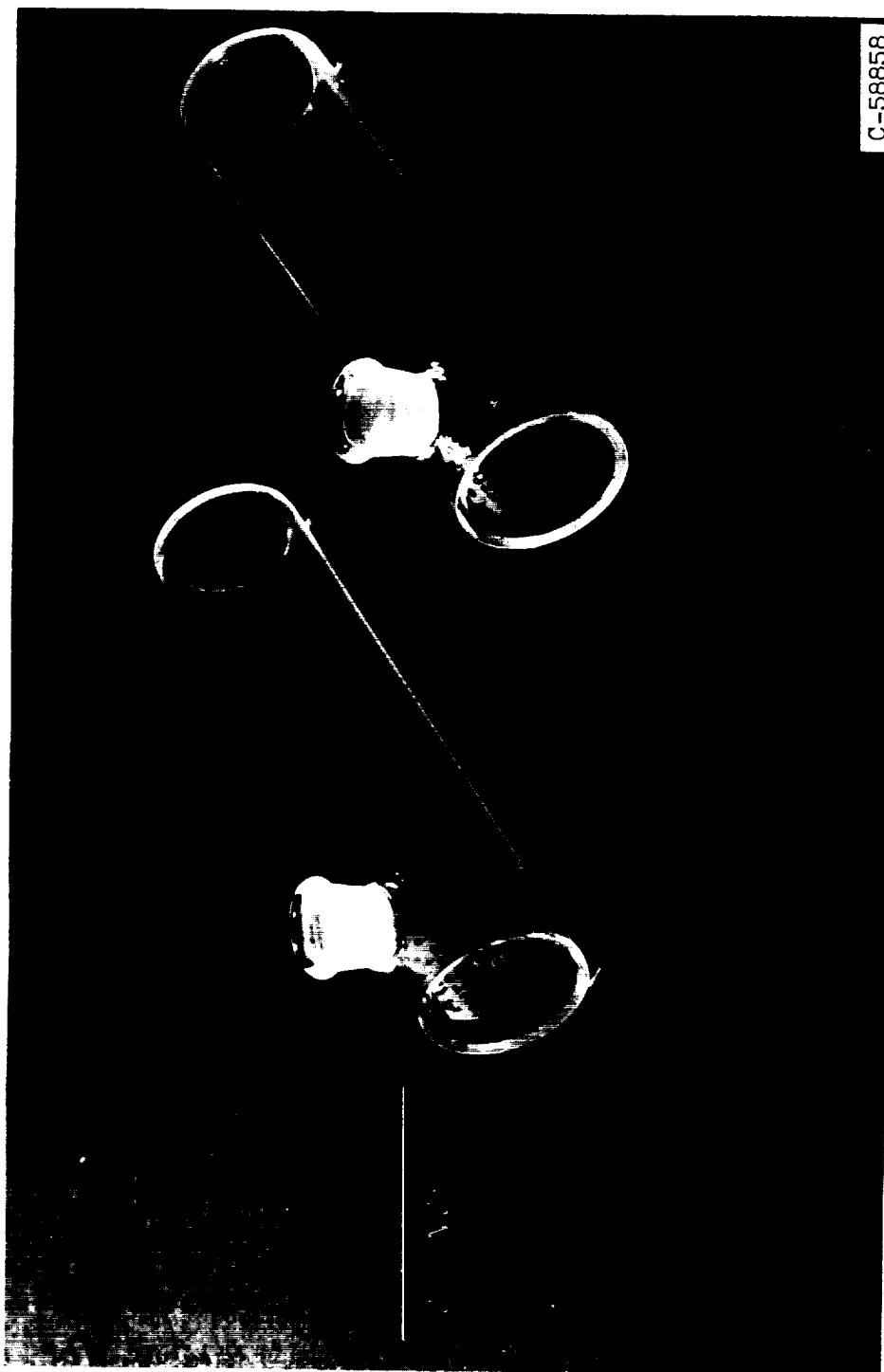
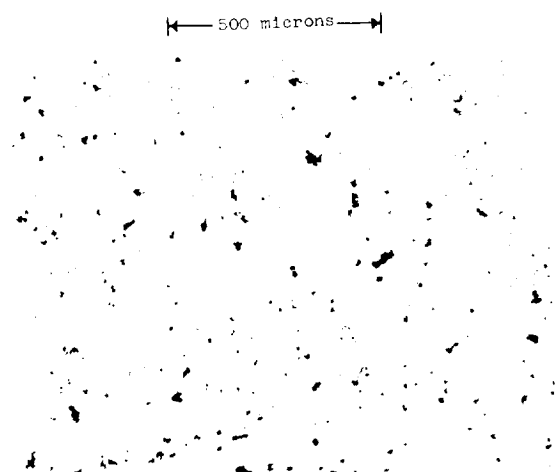
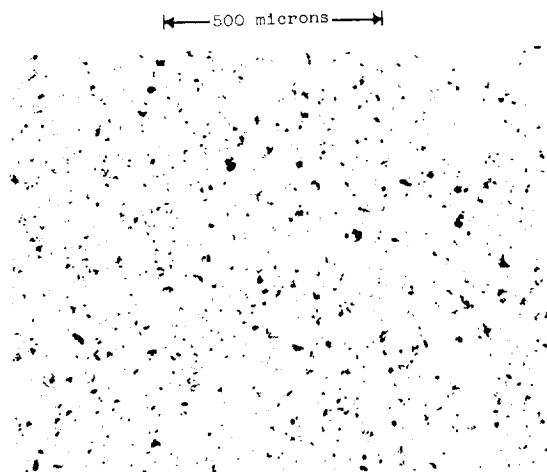


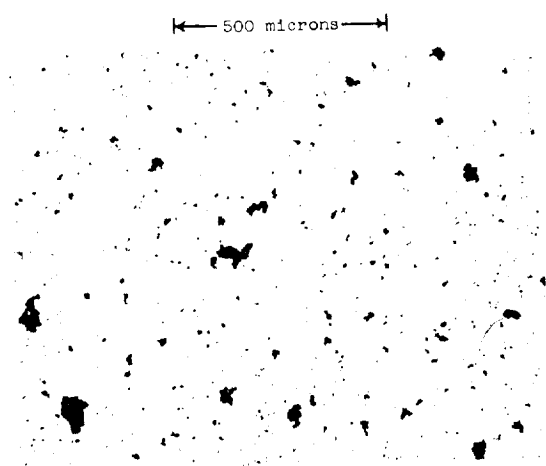
Figure 3. - Matched quartz absorption cells for spectrophotometer.



(a) Lampblack carbon; particle diameter, 0.45 micron; X100.



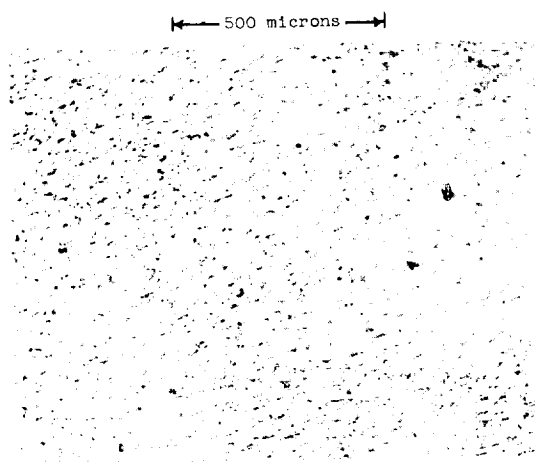
(b) Ax-coke carbon; particle diameter, 1.4 microns; X100.



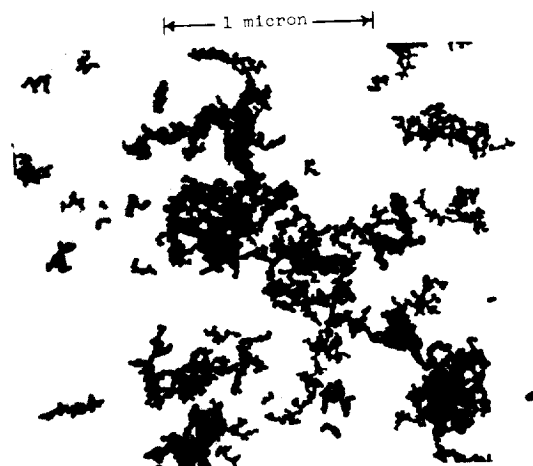
(c) Monarch carbon; particle diameter, 0.15 micron; X100.



(d) Carbolac carbon; particle diameter, 0.08 micron; X100.



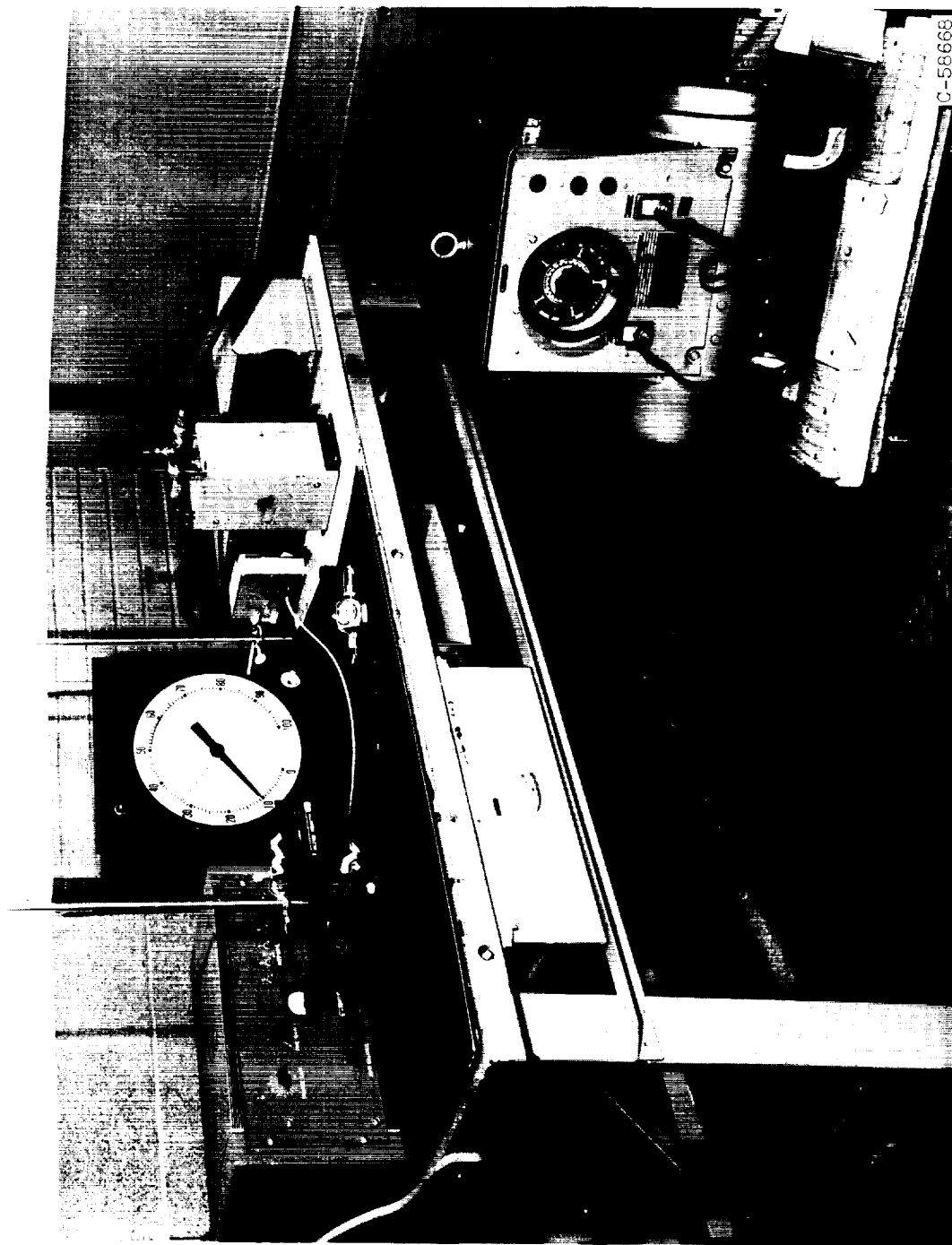
(e) Aluminum oxide; particle diameter, 0.02 micron; X100.



(f) Submicron tungsten; particle diameter, 0.02 micron; X50,000.

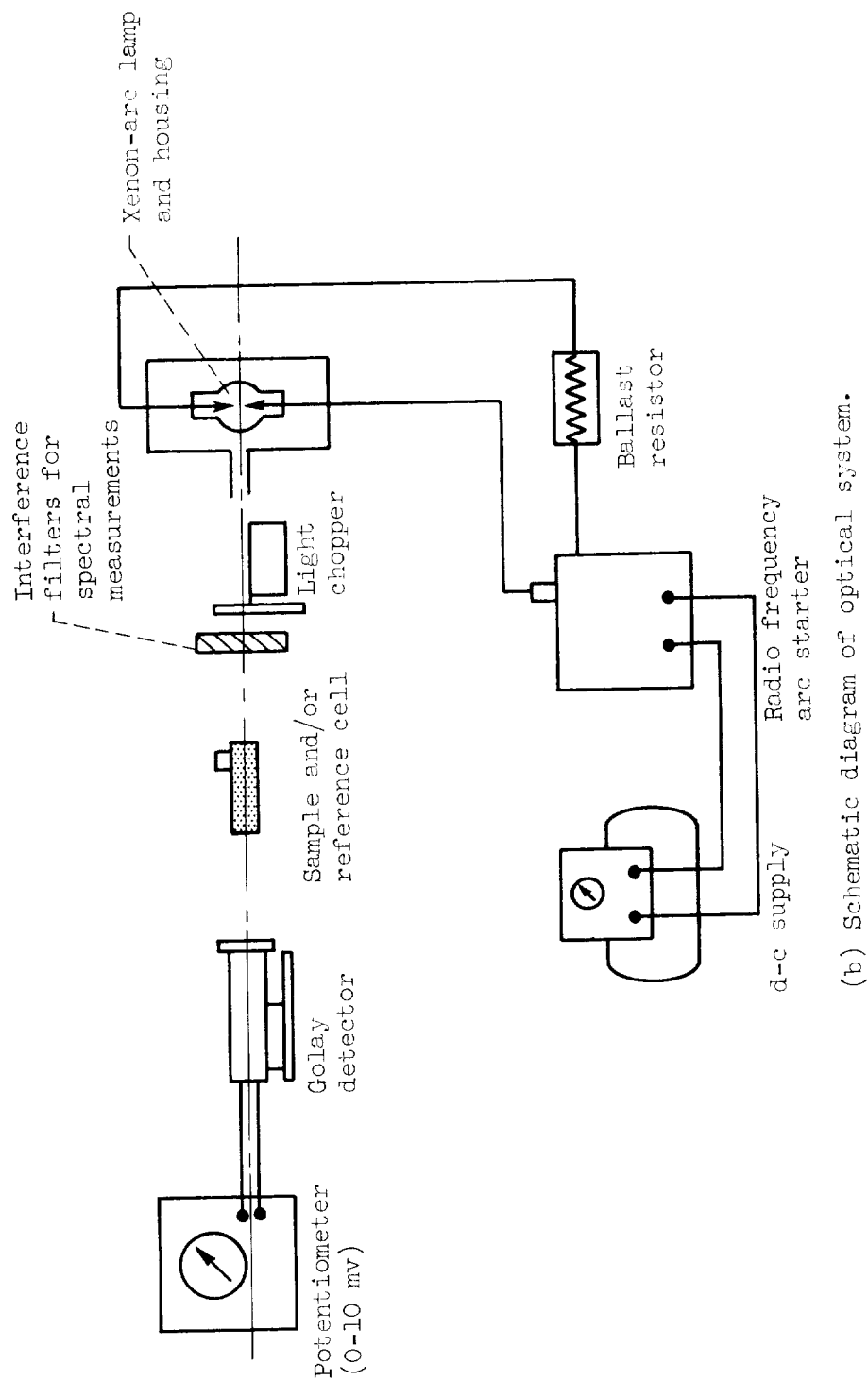
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Figure 4. - Photomicrographs of powder samples.



(a) Overall view of system.

Figure 5. - Xenon-arc total-transmissivity apparatus.



(b) Schematic diagram of optical system.

Figure 5. - Concluded. Xenon-arc total-transmissivity apparatus.

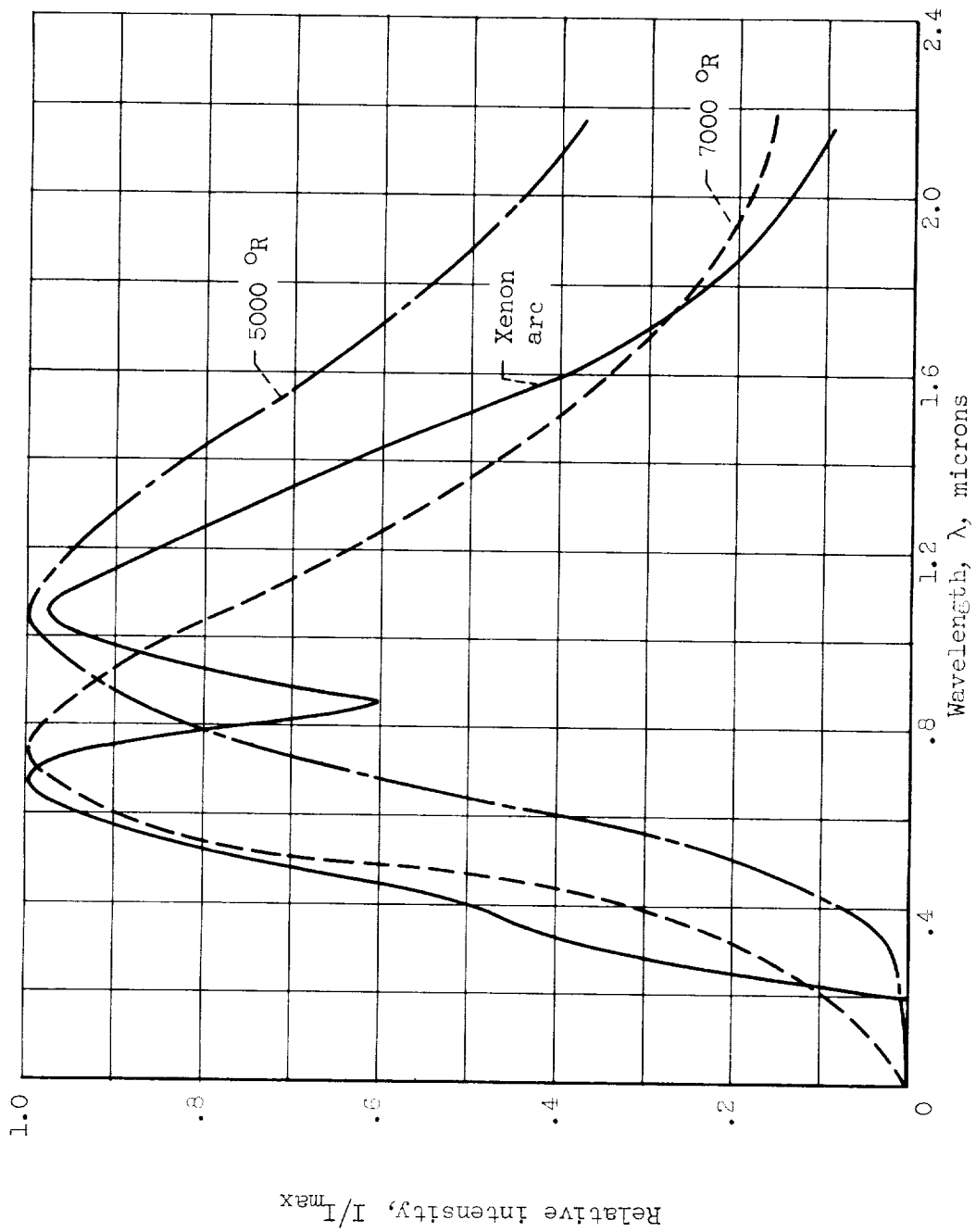


Figure 6. - Comparison of actual spectral distribution of xenon arc with blackbody distribution temperatures of 5000° and 7000° R.

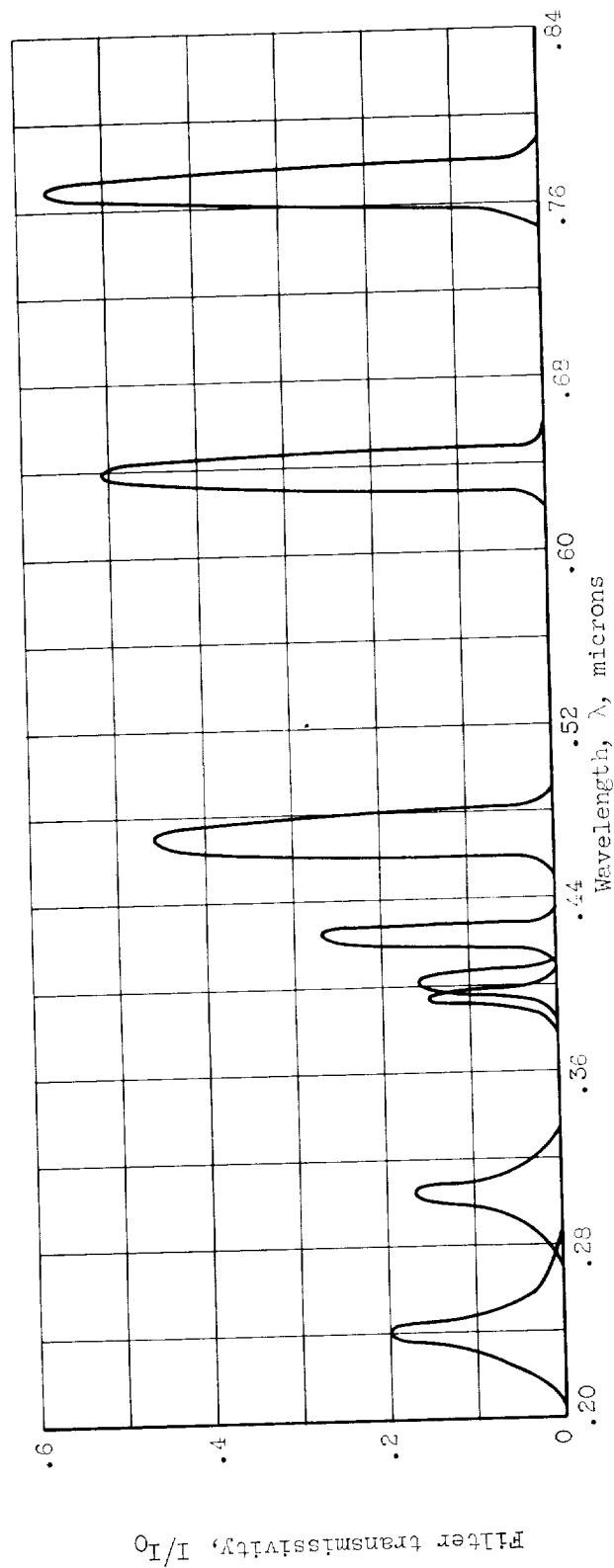


Figure 7. - Interference filter transmission curves.

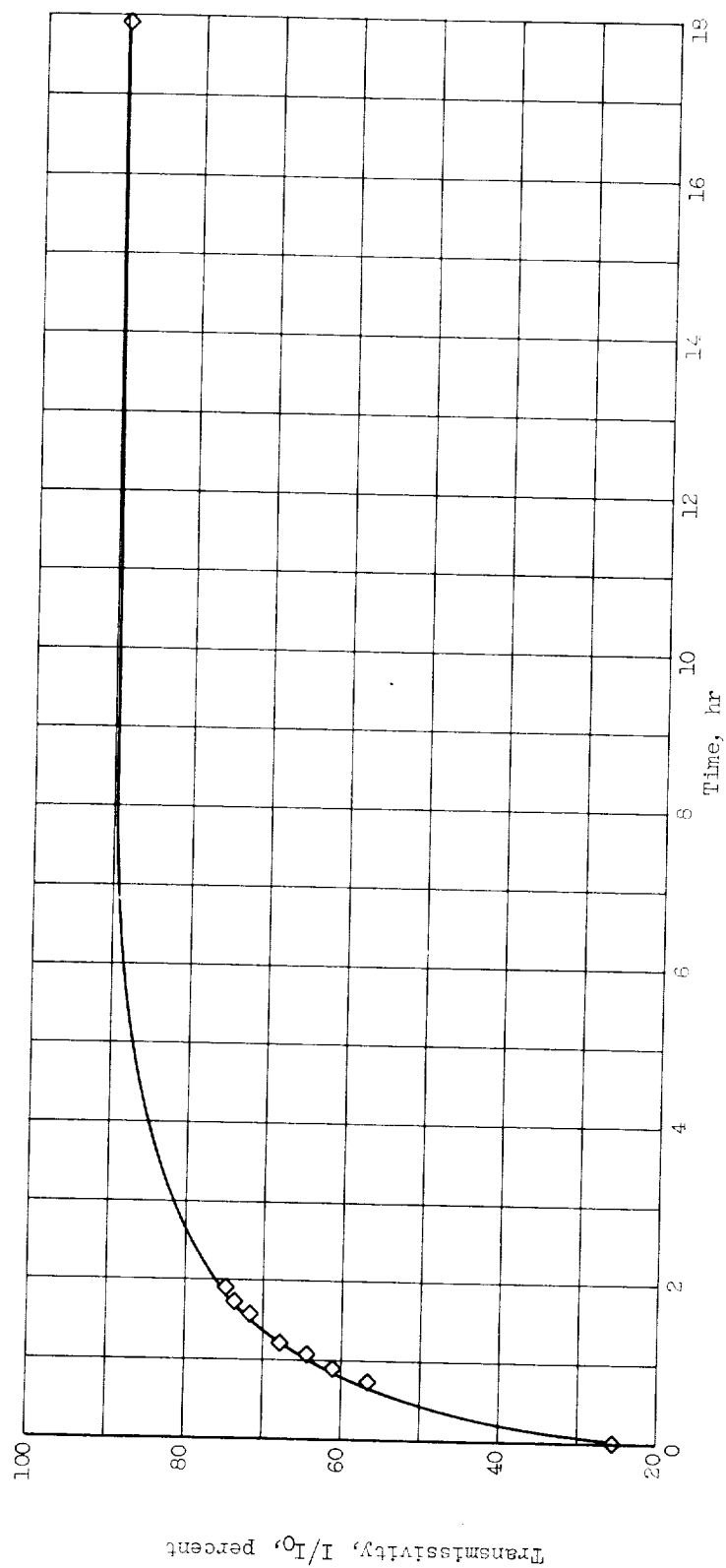


Figure 8. - Effect of particle settling on transmissivity; 0.08-micron-diameter carbon particles suspended in water.

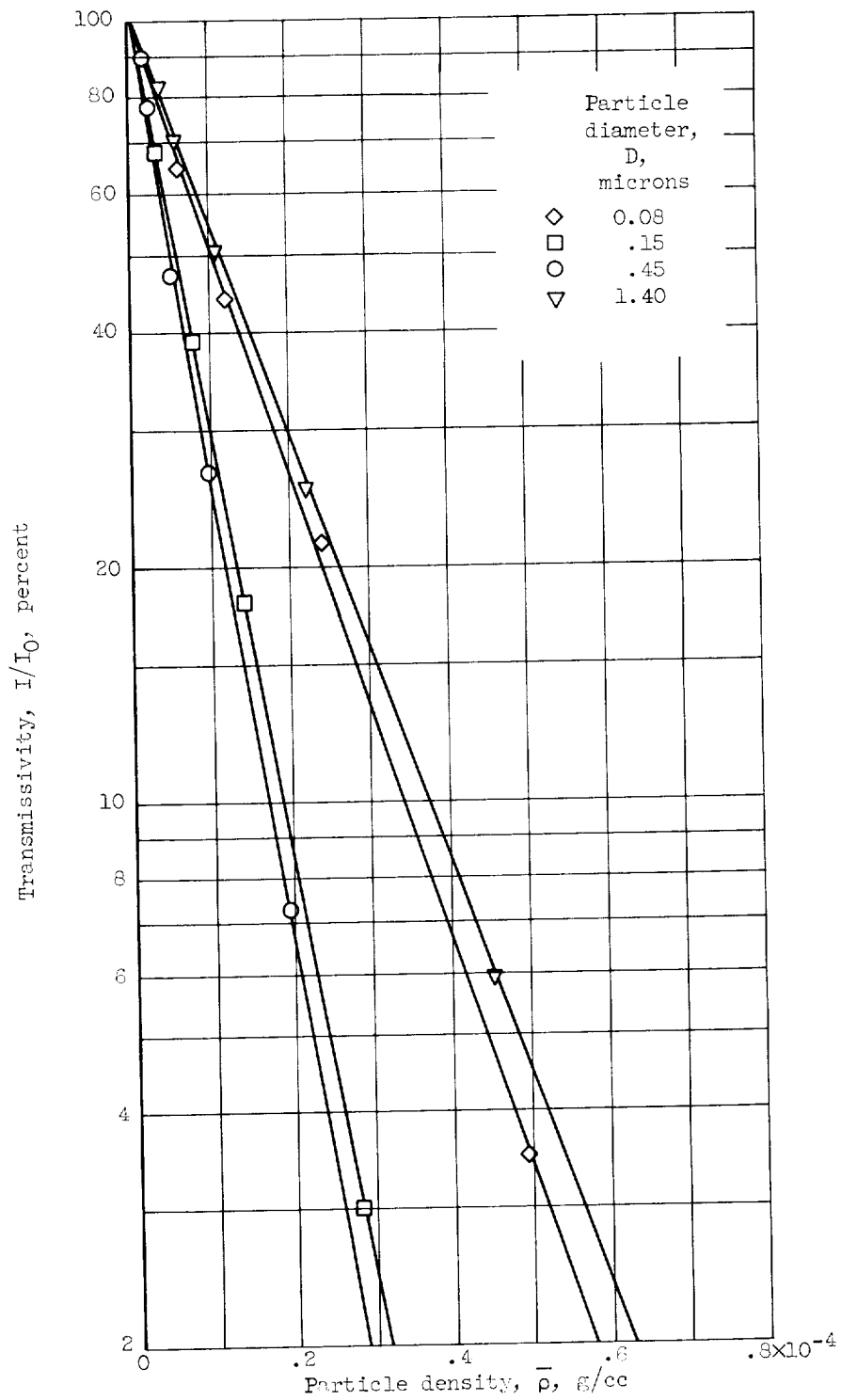


Figure 9. - Effect of particle concentration on transmissivity; monochromatic light of wavelength 0.360 micron; path length, 10 centimeters.

Figure 10. - Correlation of al_i spectral data.

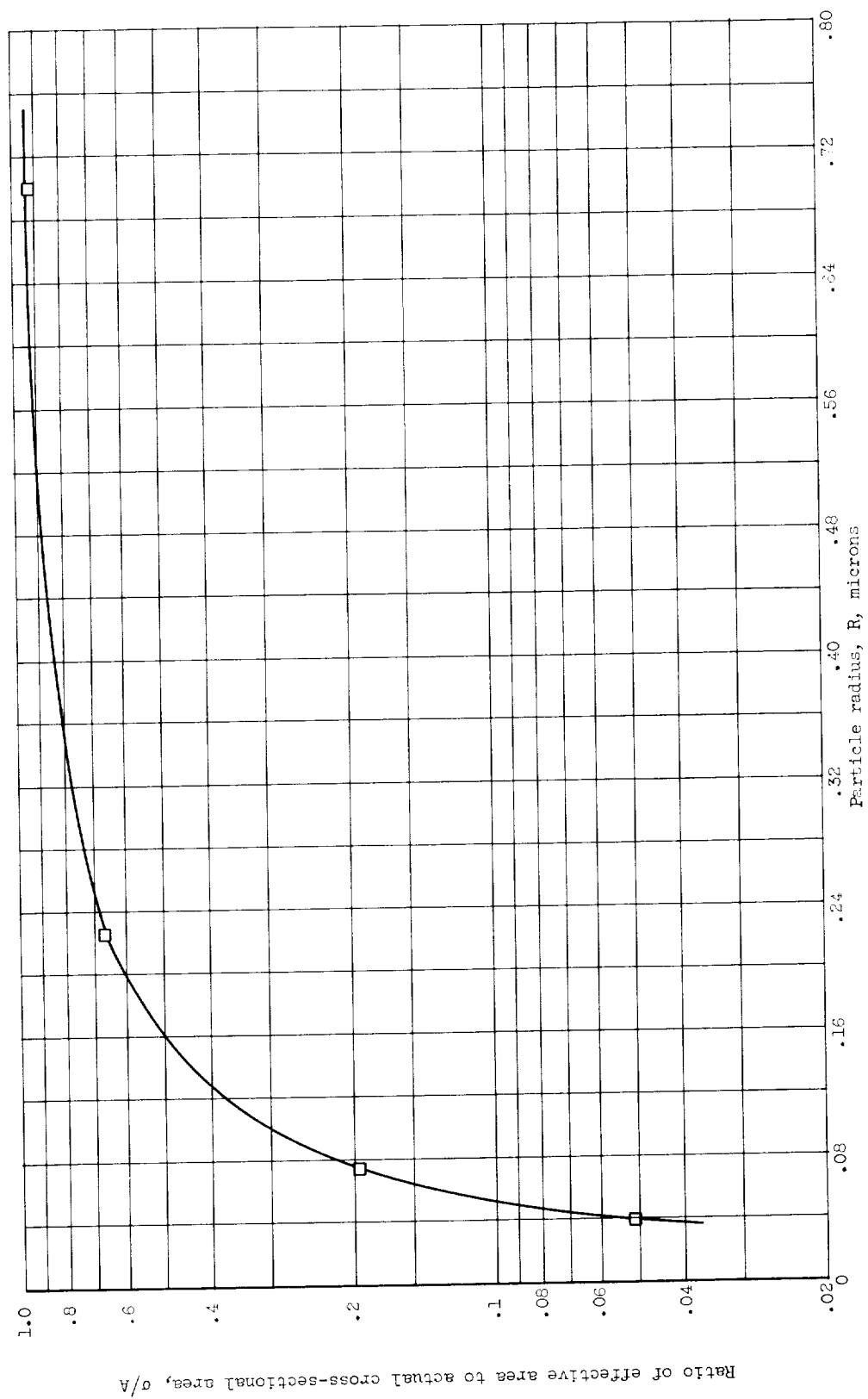
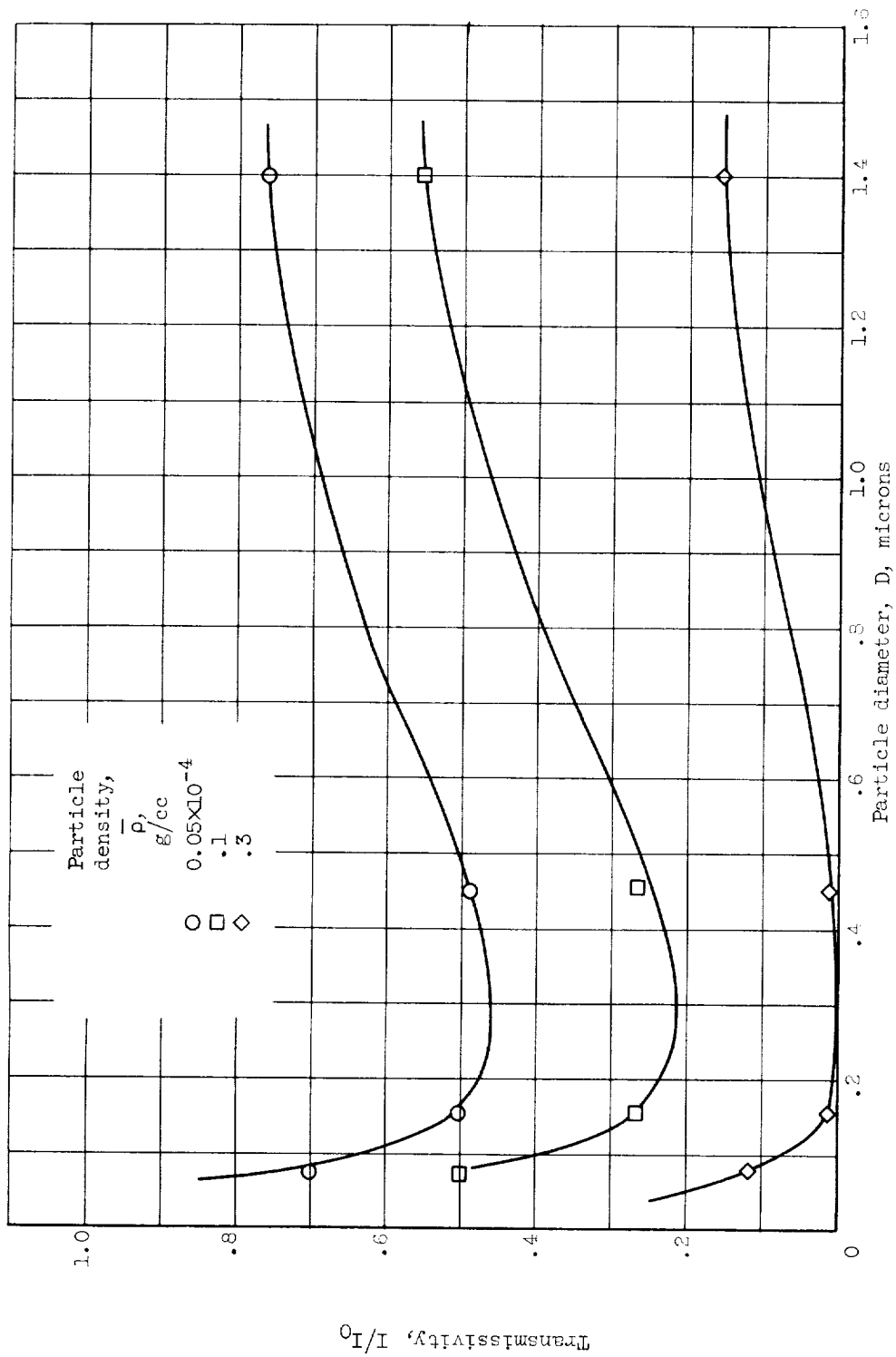
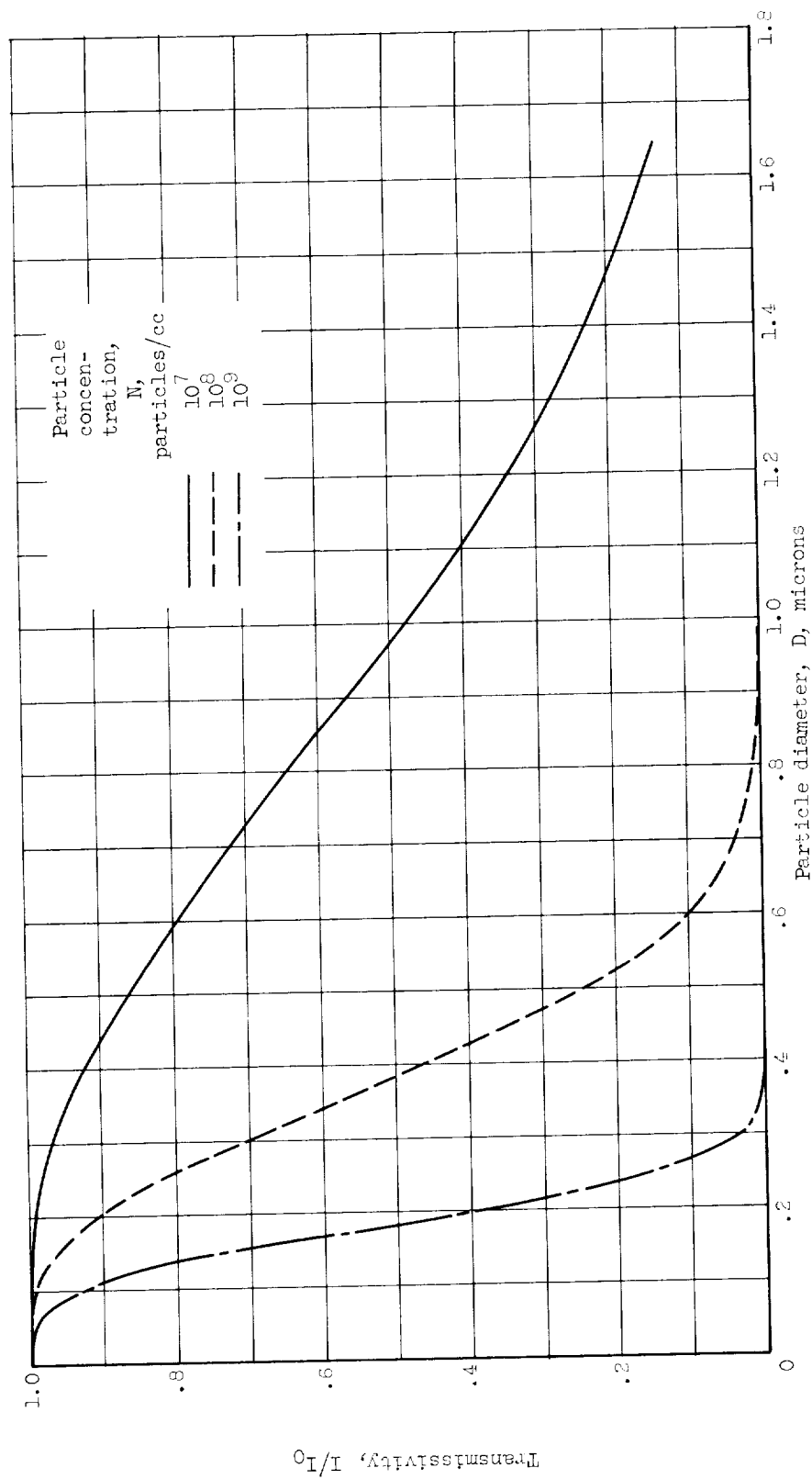


Figure 11. - Variation of ratio of effective area to cross-sectional area as function of particle radius for carbon powders.



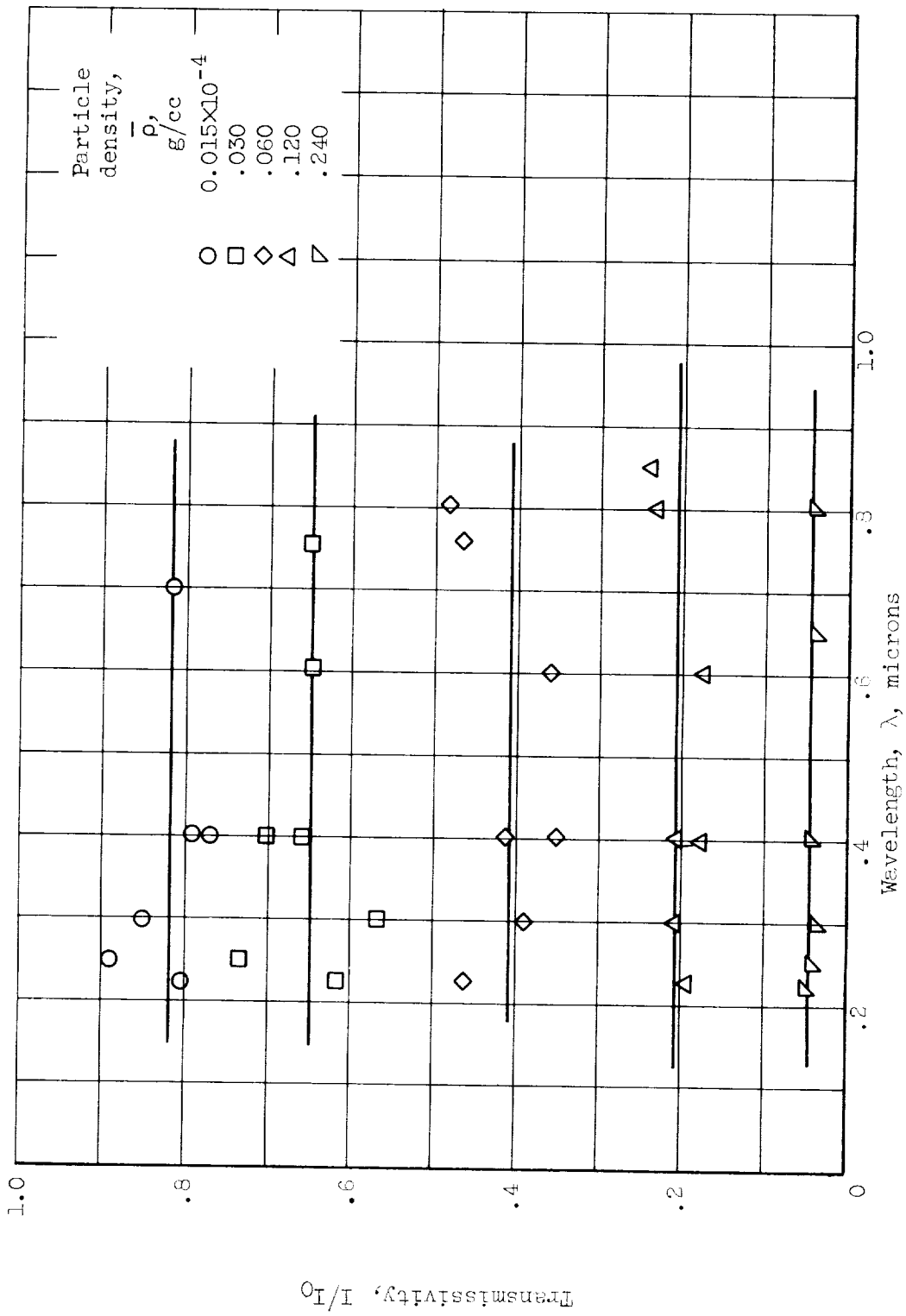
(a) Constant particle density (obtained from fig. 10).

Figure 12. - Effect of particle size on transmissivity; wavelength, 0.36 micron; path length, 10 centimeters.



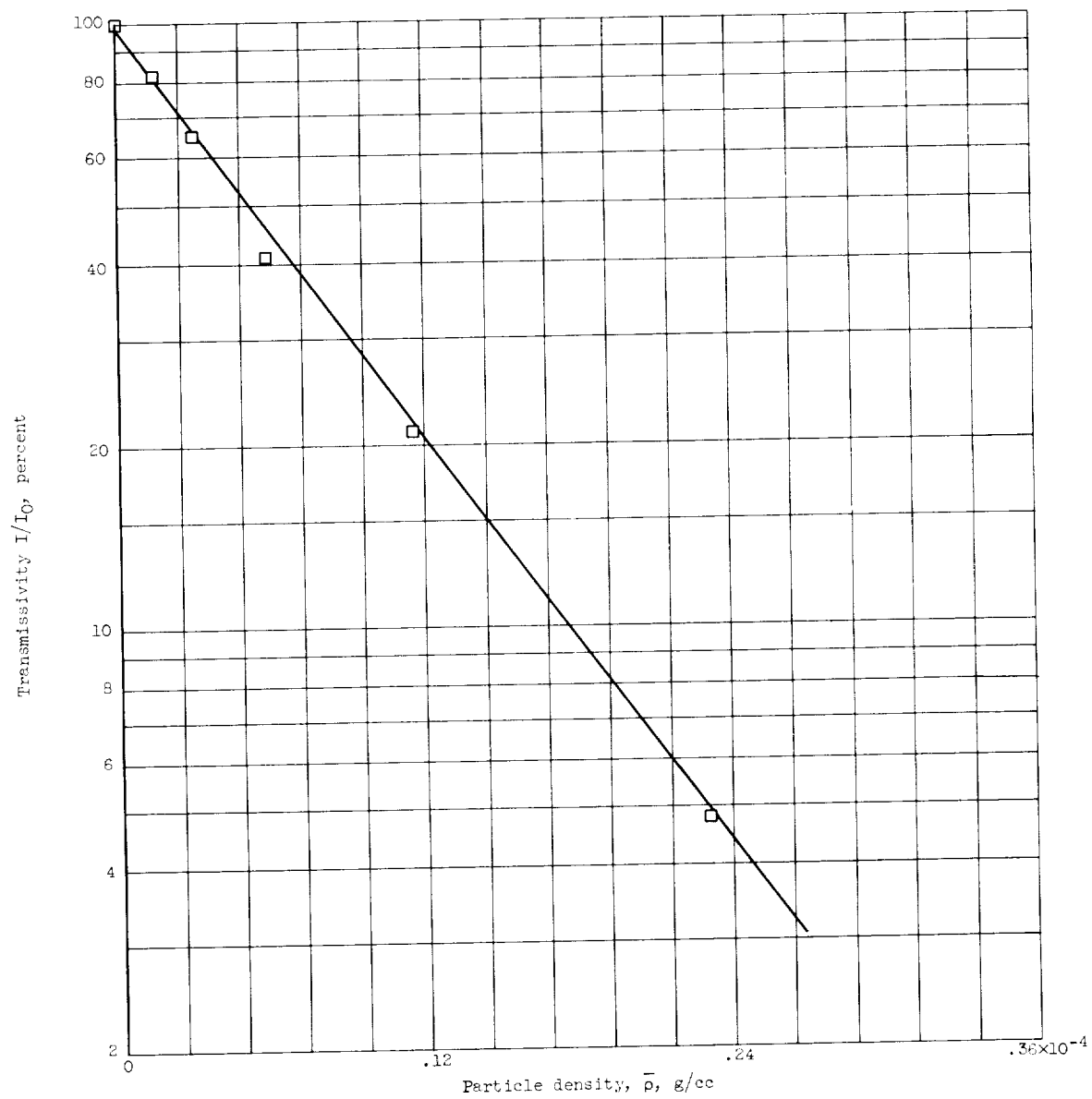
(b) Constant particle concentration.

Figure 12. - Concluded. Effect of particle size on transmissivity; wavelength, 0.36 micron; path length, 10 centimeters.



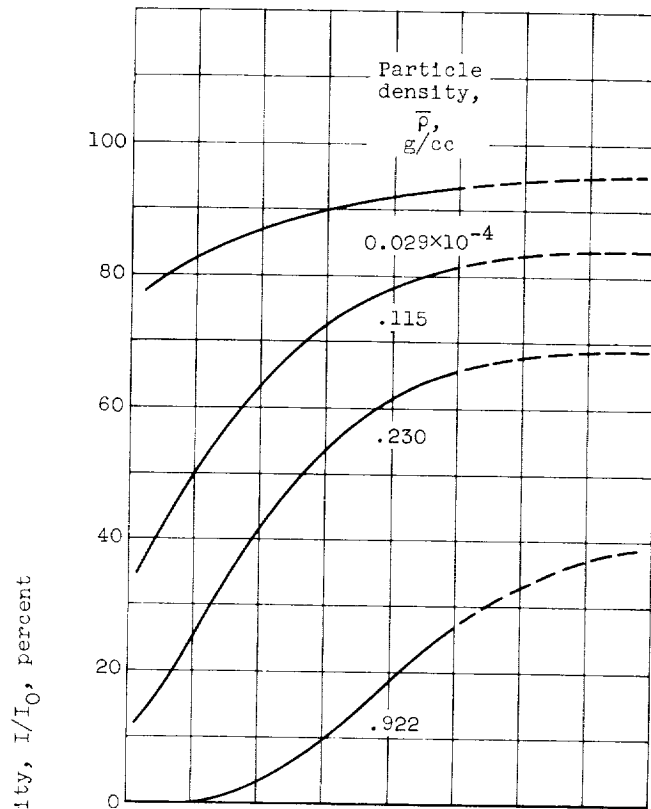
(a) Transmissivity at various wavelengths; path length, 10 centimeters.

Figure 13. - Spectral transmissivity of 0.15-micron-diameter carbon particles.

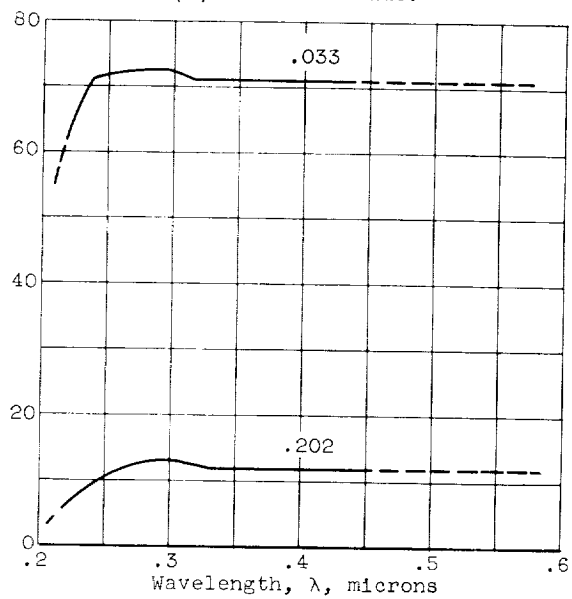


(b) Transmissivity at various particle densities.

Figure 13. - Concluded. Spectral transmissivity of 0.15-micron-diameter carbon particles.



(a) Aluminum oxide.



(b) Tungsten.

Figure 14. - Spectral transmissivity of noncarbon particles; path length, 10 centimeters; particle diameter, 0.02 micron.

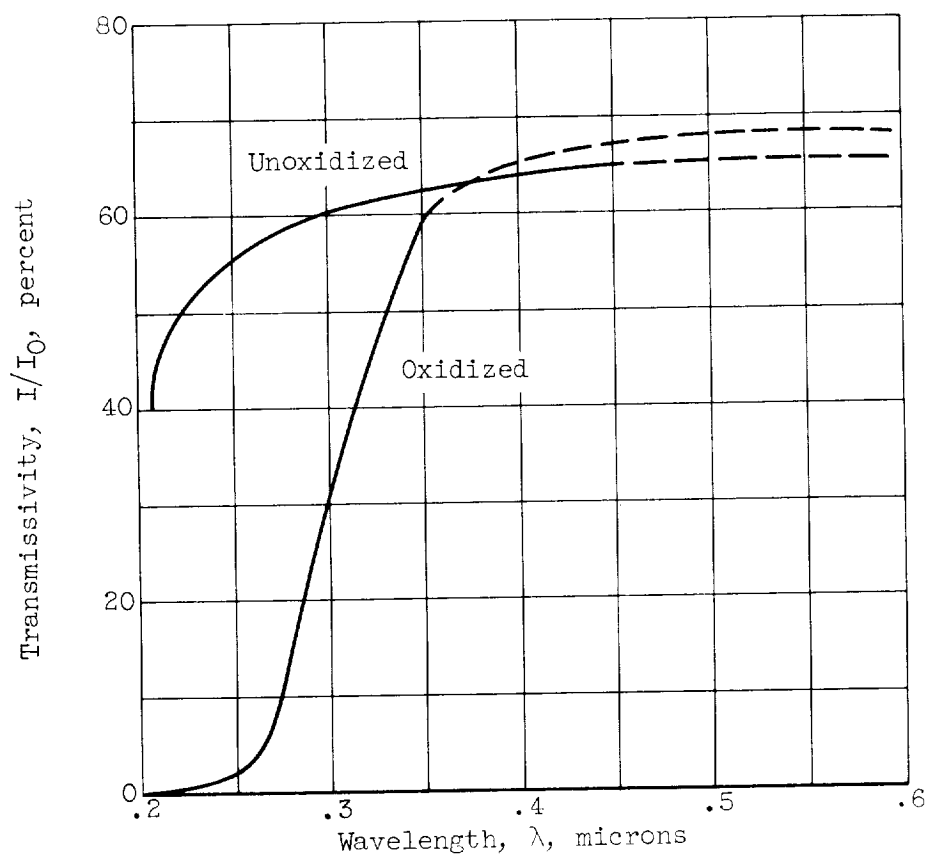


Figure 15. - Effect of oxidation on tungsten spectral transmissivity; path length, 10 centimeters; particle diameter, 0.032 micron.

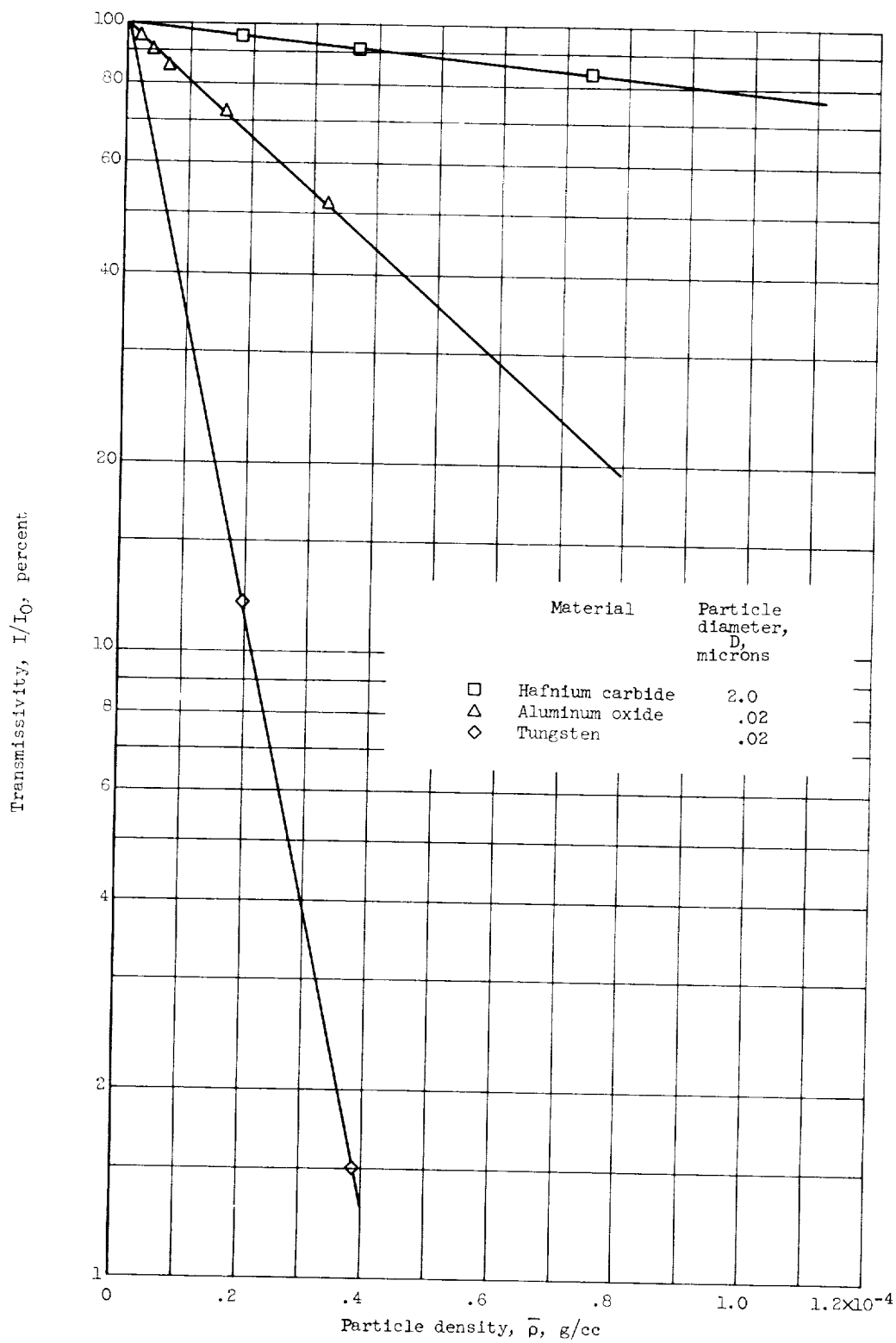


Figure 16. - Effect of concentration on transmissivity for noncarbon particles; wavelength, 0.36 micron; path length, 10 centimeters.

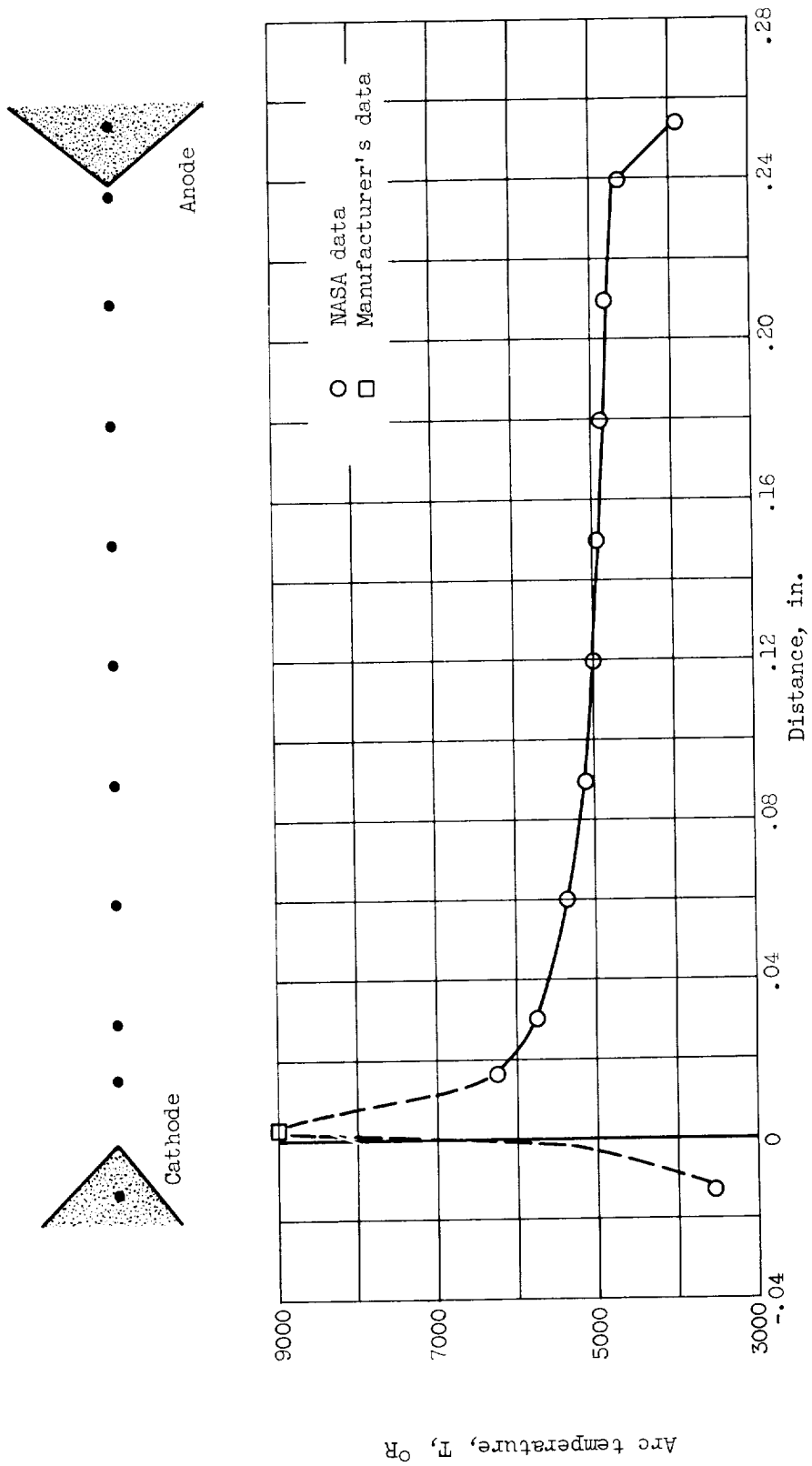
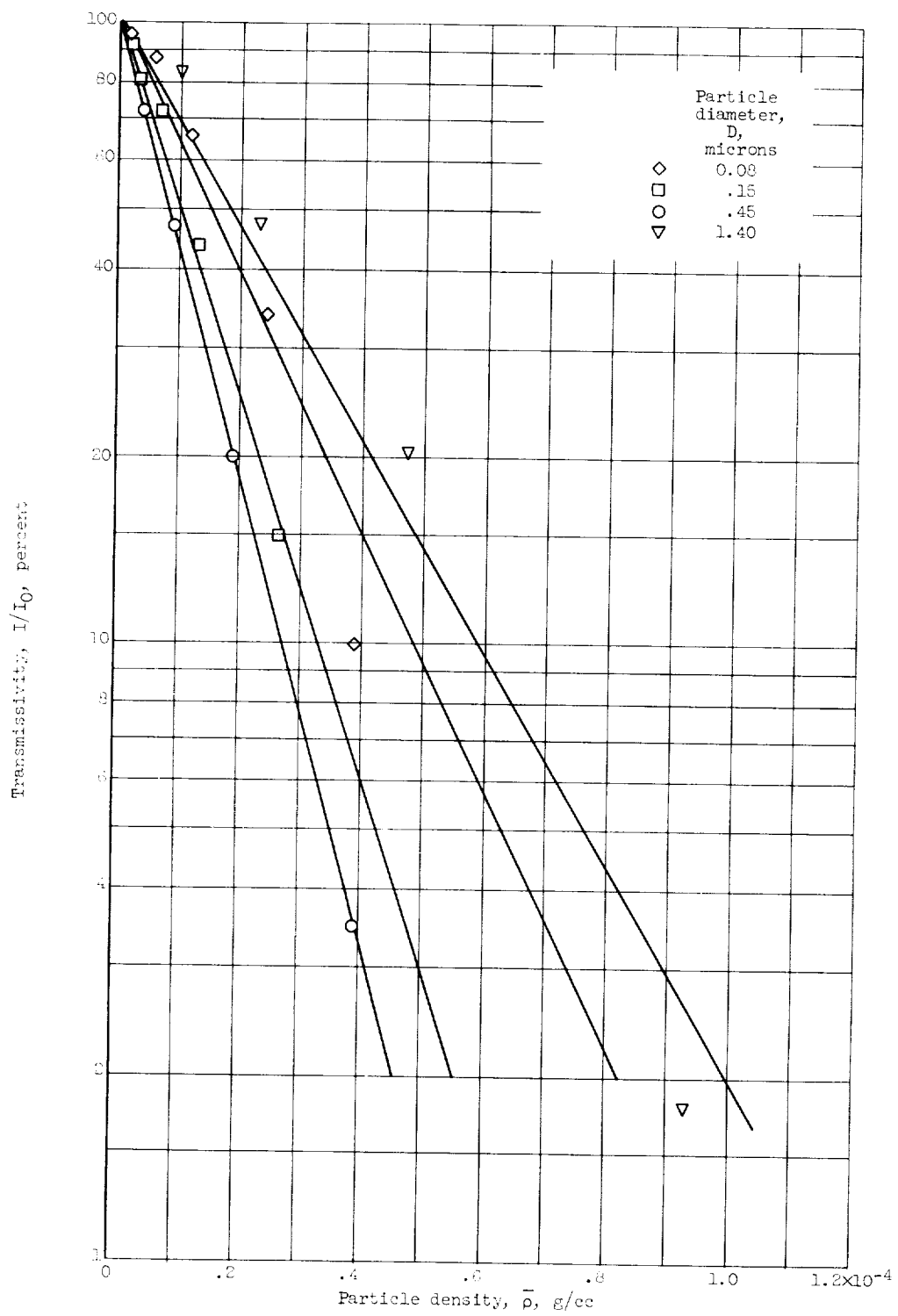
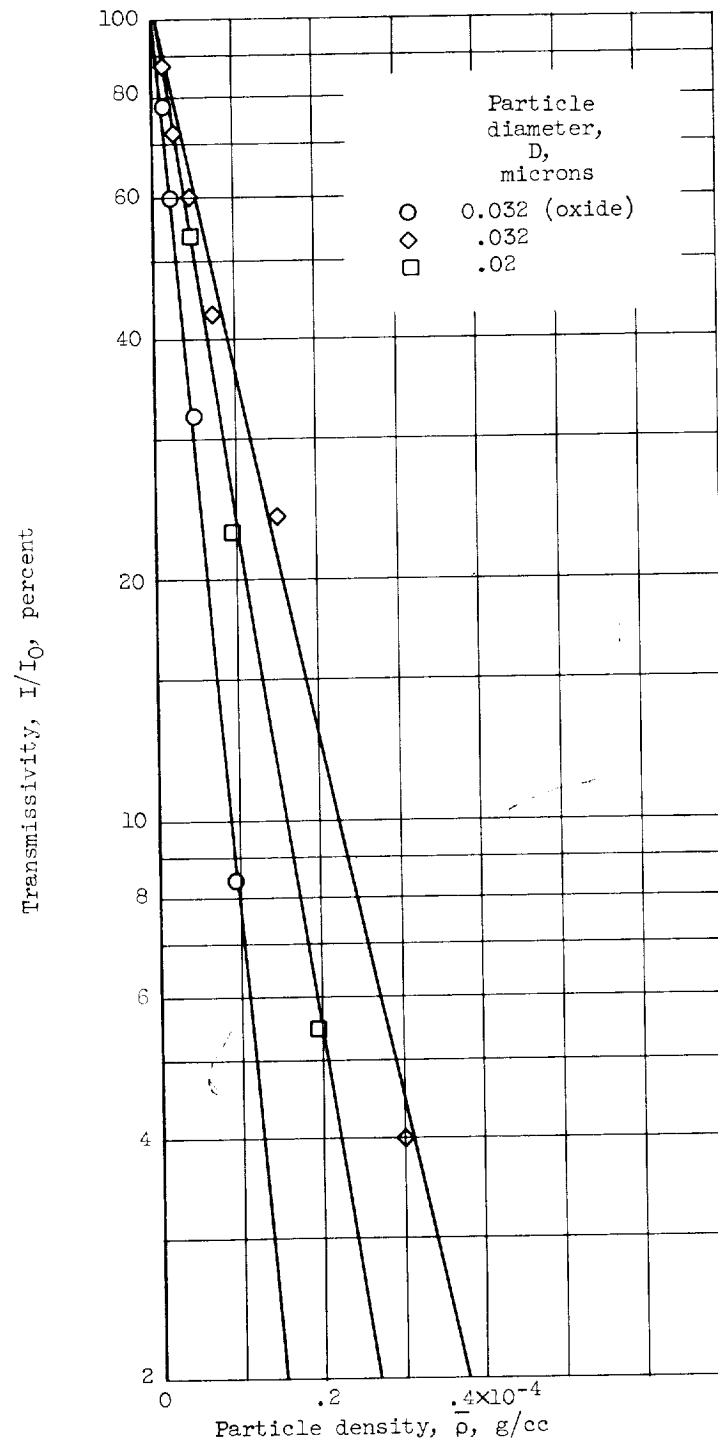


Figure 17. - Xenon arc temperature distribution.



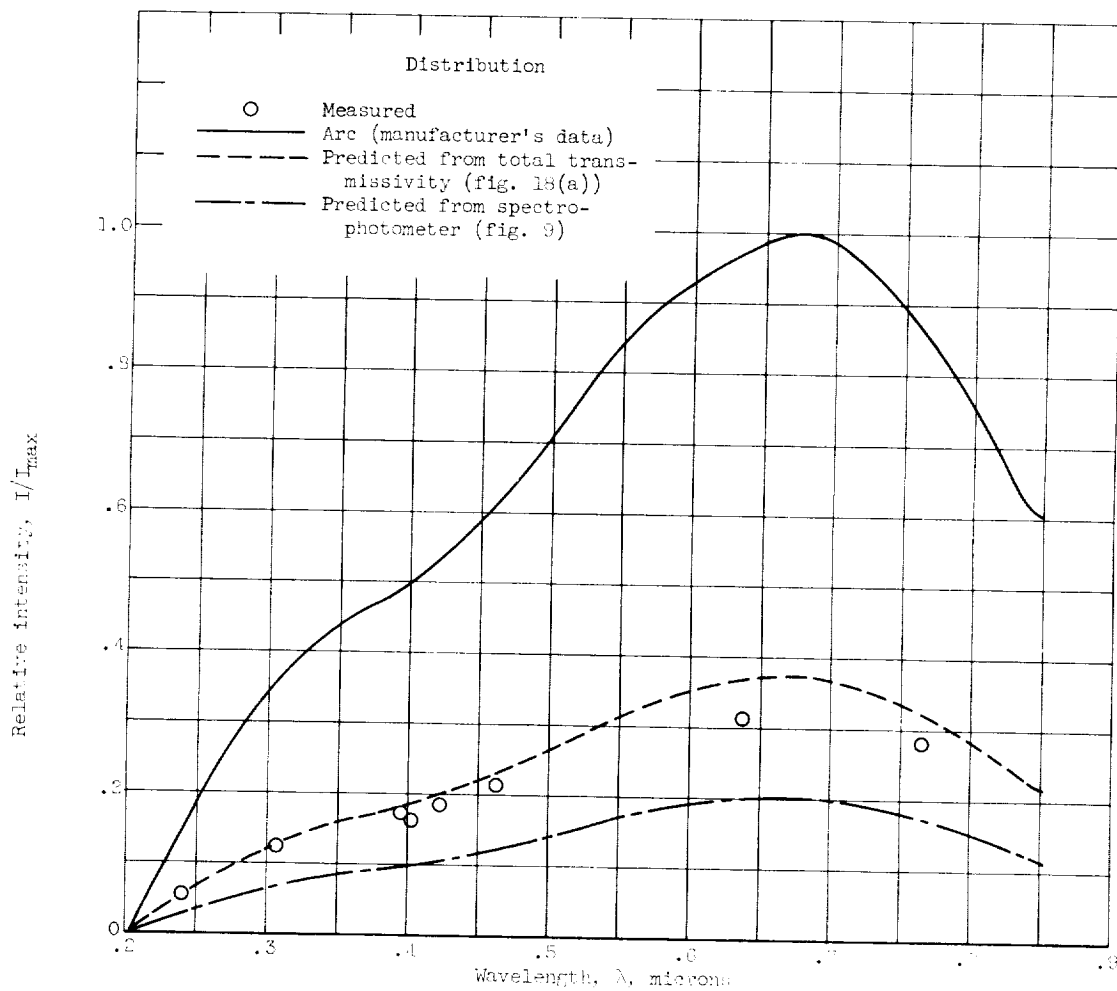
(a) Carbon powders.

Figure 14. - Effect of concentration on total transmissivity measured with xenon arc.



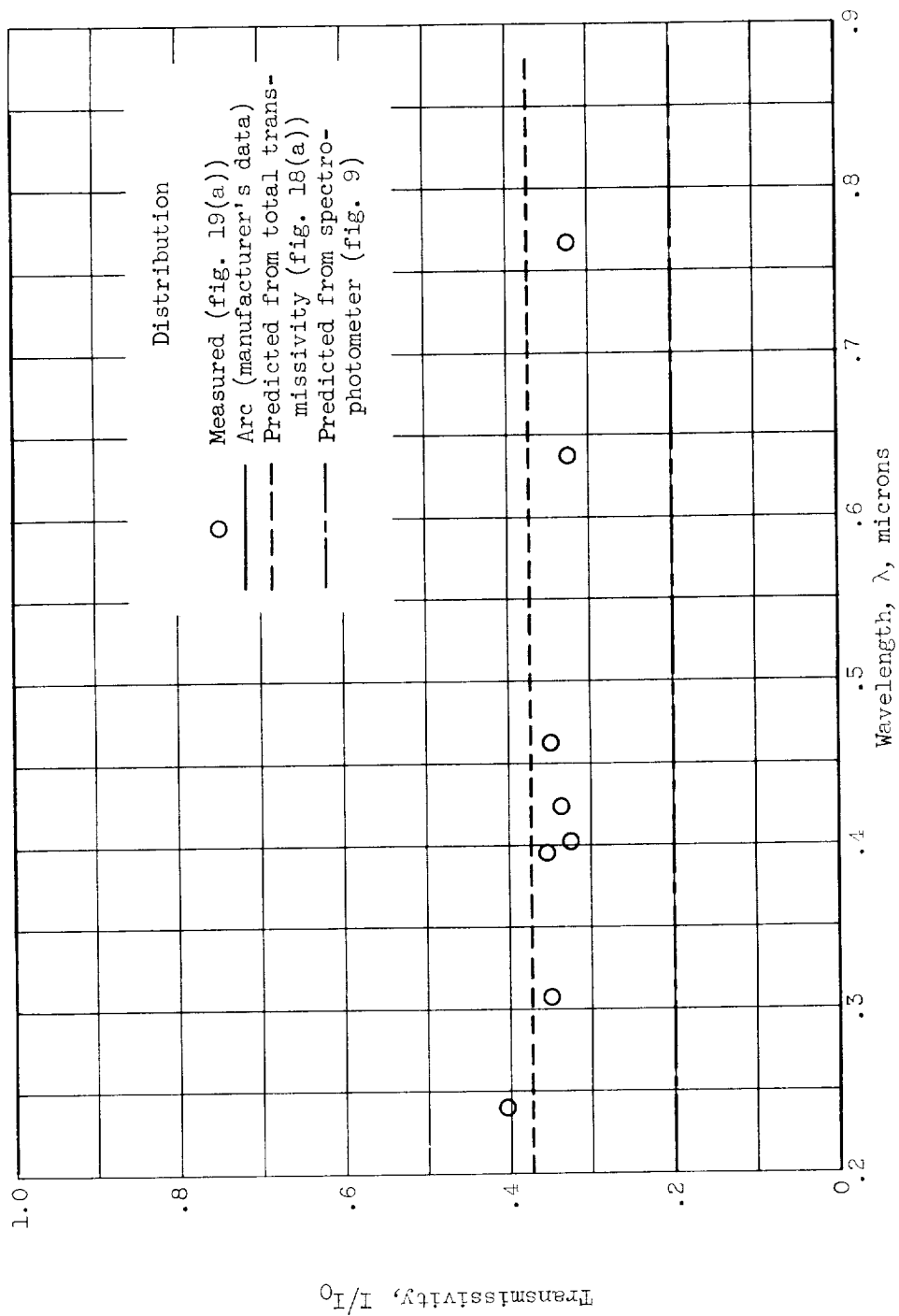
(b) Tungsten powders.

Figure 18. - Concluded. Effect of concentration on total transmissivity, measured with xenon arc.



(a) Actual distribution.

Figure 10. - Spectral transmissivity of 0.08-micron-diameter carbon particles measured with xenon arc.



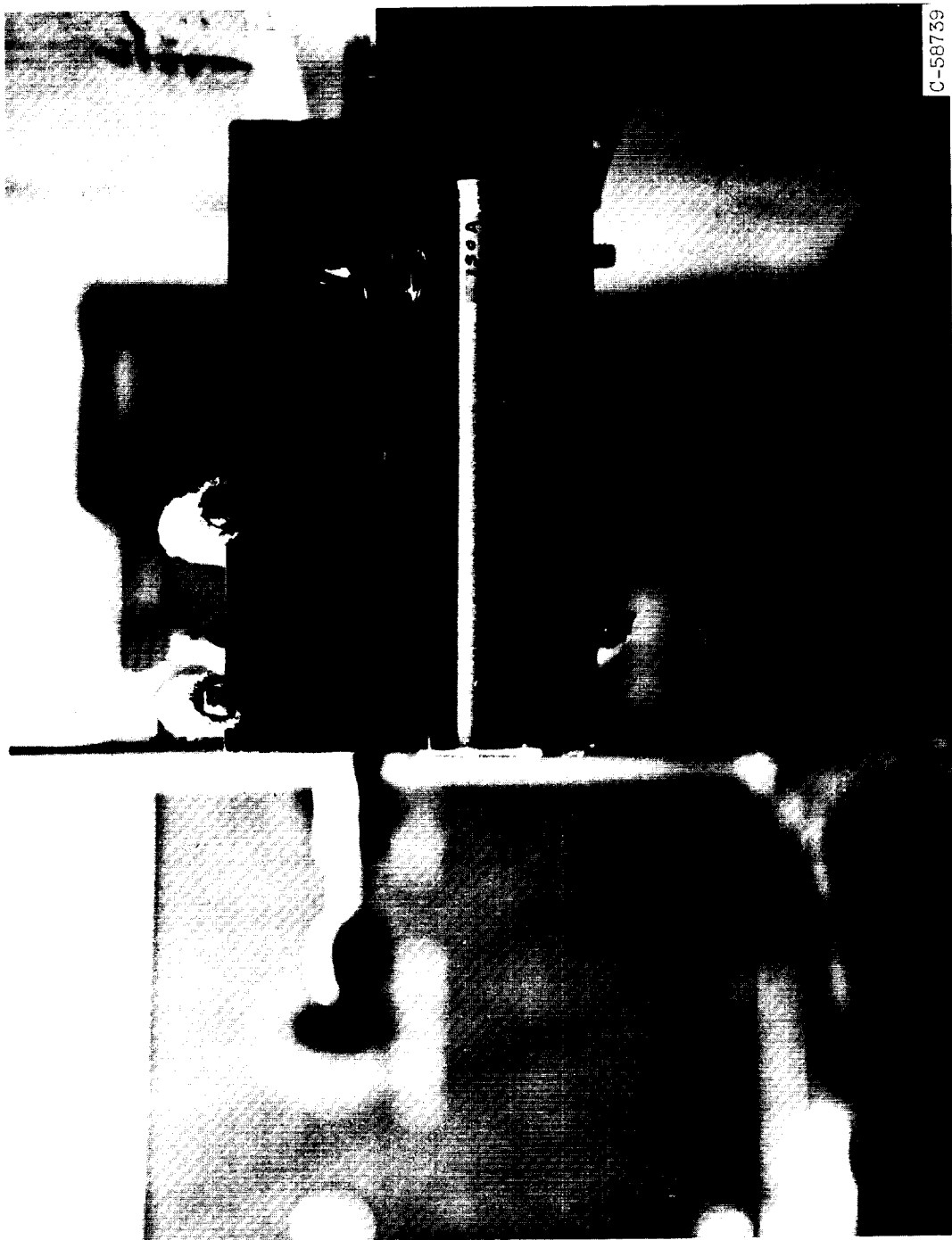
(b) Normalized distribution.

Figure 19. - Concluded. Spectral transmissivity of 0.08-micron-diameter carbon particles measured with xenon arc.



(a) End view.

Figure 20. - Particle-filled absorption cells.



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(b) Side view.

Figure 20. - Concluded. Particle-filled absorption cells.

